Chapter 2

Principles of Integrated Urban Water Management

James P. Heaney

Introduction

The purpose of this chapter is to review the literature on innovative urban developments, in general; evaluate principles of sustainability; and present the urban stormwater management problem within this broader context.

The Neighborhood Spatial Scale

The spatial scales for urban developments to be evaluated in this report are defined as follows:

1. Individual parcel: the smallest spatial scale consisting of an individual lot that may contain a house, apartment, commercial, industrial, or public activity.
2. Block: collection of parcels bounded by streets. For example, in higher density, older neighborhoods with gridiron streets, the typical area of a block is 1/8 x 1/16 of a mile or five acres. Blocks tend to be larger in area for contemporary lower density developments with block sizes being as large as 20 acres in size.
3. Subdivision: single land development, typically with the same land uses. Subdivisions are assumed to range in size from 25 to 100 acres.
4. Neighborhood: mixture of residential, commercial, public, and perhaps industrial land uses. The neighborhood is assumed to be an integrated, partially self-sustained, urban system. Typical sizes would be 100-1,000 acres.
5. New Town: cluster of neighborhoods designed to be largely self-sustaining in that the town provides sufficient employment opportunities for the local residents. Population sizes range from 20,000 to 60,000 people.

While the scope of this report are developments with populations less than 50,000 people, the area can either be greenfield (previously undeveloped land) or brownfield (urban redevelopment).

Trends in Urbanization

Historical Patterns

Certain background information helps to understand and evaluate future neighborhood stormwater systems. Examples are understanding historical land use patterns, factors stimulating changes in those land use patterns, and projecting expected future patterns of urban land use and the extent to which urban infrastructure might influence, or be influenced, by these changes.

Cities evolve in response to the inhabitants' needs for mutual self-protection, commerce, education, and cultural exchange. The late 1800's signaled the end of the "pioneer era" in the United States during which people migrated from place to place in search of a better way of life. For the first 20 years of the 20th century, infrastructure in cities focused on non-transportation related needs. However, the growing importance of the automobile, beginning in the 1920's, forced city managers to devote an increasing portion of their budgets to accommodating this new mode of transportation. Prior to World War II, U.S. cities developed around the concept of mixed neighborhoods as part of villages, towns, and cities. Beginning in the late 1940's, suburbia began to dominate urban America. Early suburbia had its origins in the late 19th century with urban dwellers seeking to escape the blighted conditions of cities. Suburban living in the late 19th century was made possible by commuter trains that provided reasonable access to cities from outlying areas.

Impact of the Automobile

The automobile is having a profound impact on urban developments during the 20th century. A summary of trends in population and automobile use in the United States from 1915 to 1994 is shown in Table 2-1. During this period, the U.S population grew by a factor of 2.6 from 100 to 261 million people and the number of automobiles grew by a factor of 80 from 2.5 million to nearly 200 million. The most dramatic growth in automobiles occurred since World War II. For example, from 1945 to 1955, the number of automobiles doubled from 31 million to 62.8 million. From 1955 to 1995, the number of automobiles tripled to over 200 million vehicles. The trends in growth of population and automobiles, shown in Figure 2-1, indicate that the rate of increase of vehicles is much greater than population growth.

The trend in vehicles per capita is shown in Figure 2-2. At present, there are 0.76 vehicles per capita. Perhaps, this is a saturation level based on the percentage of the population that is older than the minimum driving age. For example, 79.9% of the U.S. population is over 13 years old (National Safety Council 1995).

The vehicle miles traveled (VMT) per capita has continued to rise at a steady rate since 1945 as shown in Figure 2-3. Projections for the State of Colorado indicate that the 1995 VMT of 10,000 is expected to increase to 11,130 by the year 2020 (Yuhnke 1997). The average American drives twice as much as the average European or Japanese citizen (Kunstler 1996). Americans use cars for 82% of their trips compared to 48% for Germans, 47% for the French, and 45% for the British (Kunstler 1996). Between 1960 and 1990, Americans commuting by car increased from 69.5% to 86.5% while commuting by public transit decreased from 12.6% to 5.3% and walking decreased from 10.4% to 3.9% (Goldstein 1997).

With only 5% of the world's population, the United States consumes a quarter of the world's oil, half of which is used in motor vehicles (Kunstler 1996). Over 60,000 square miles of U.S. land is paved over which is 2% of the total surface area and 10% of the arable area (Kunstler 1996). The American public has subsidized this development through a combination of incentives such as large defense expenditures to protect oil producing countries, subsidized highway construction, and "free" parking. Auto tolls

Table 2-1. Changing patterns of automobile use in the U.S., 1915-1996 (Tetra Tech 1996).

Year	No. of Vehicles millions	No. of Drivers millions	Vehicle Miles/yr. Billions	Population millions	Drivers/ Population	Vehicles/ Population	Vehicles miles/ capita
1915	2.5	3.0		100	3.0%	0.03	
1920	9.2	14.0		107	13.1%	0.09	
1925	21.1	30.0	122	115	26.2%	0.18	1064
1930	26.7	40.0	206	123	32.5%	0.22	1672
1935	26.5	39.0	229	127	30.7%	0.21	1801
1940	32.5	48.0	302	132	36.3%	0.25	2285
1945	31.0	46.0	250	132	34.7%	0.23	1888
1950	49.2	62.2	458	151	41.2%	0.33	3030
1955	62.8	74.7	606	164	45.5%	0.38	3690
1960	74.5	87.4	719	180	48.6%	0.41	3997
1965	91.8	99.0	888	194	51.1%	0.47	4588
1970	111.2	111.5	1120	204	54.7%	0.55	5494
1975	137.9	129.8	1330	215	60.3%	0.64	6178
1980	161.6	145.3	1521	227	63.9%	0.71	6694
1985	177.1	156.9	1774	239	65.6%	0.74	7420
1990	192.9	167.0	2148	249	67.1%	0.77	8626
1994	199.4	175.1	2347	261	67.1%	0.76	8992

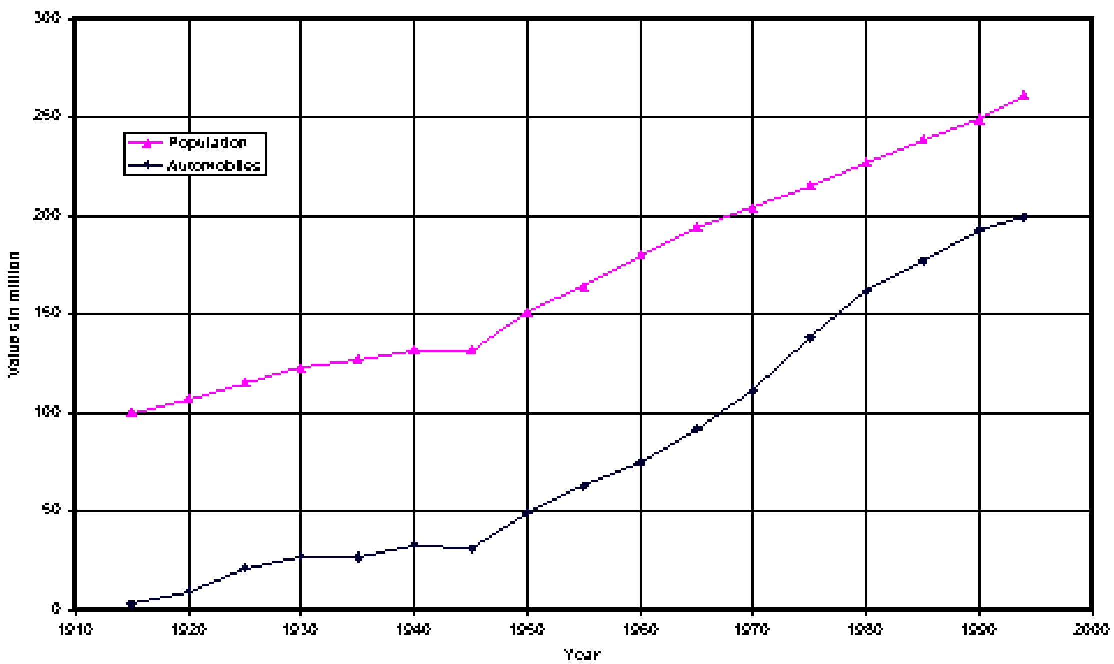

Figure 2-1. Trends in U.S. population and ownership of automobiles.

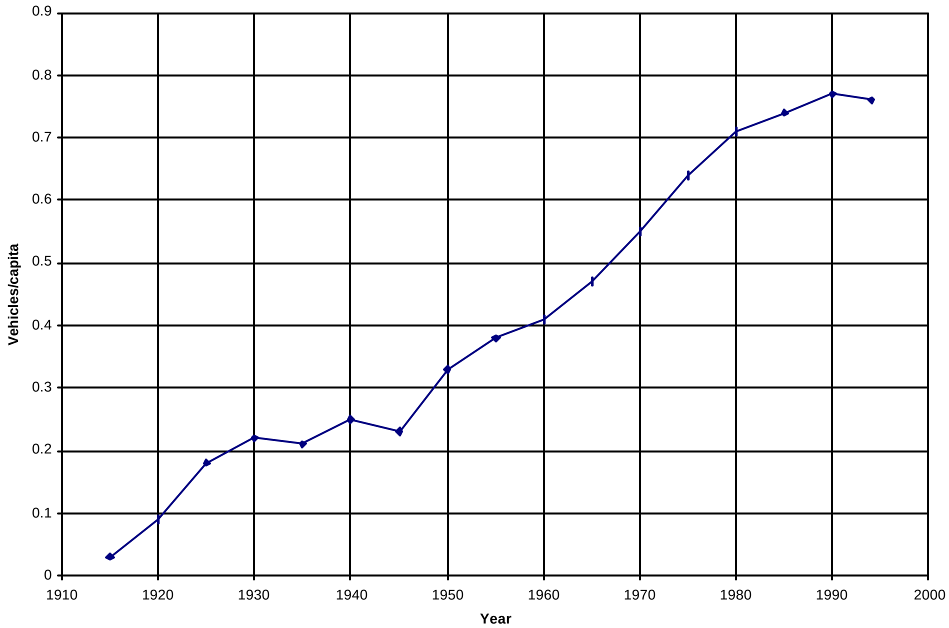

Figure 2-2. Trends in vehicles per capita in the U.S.

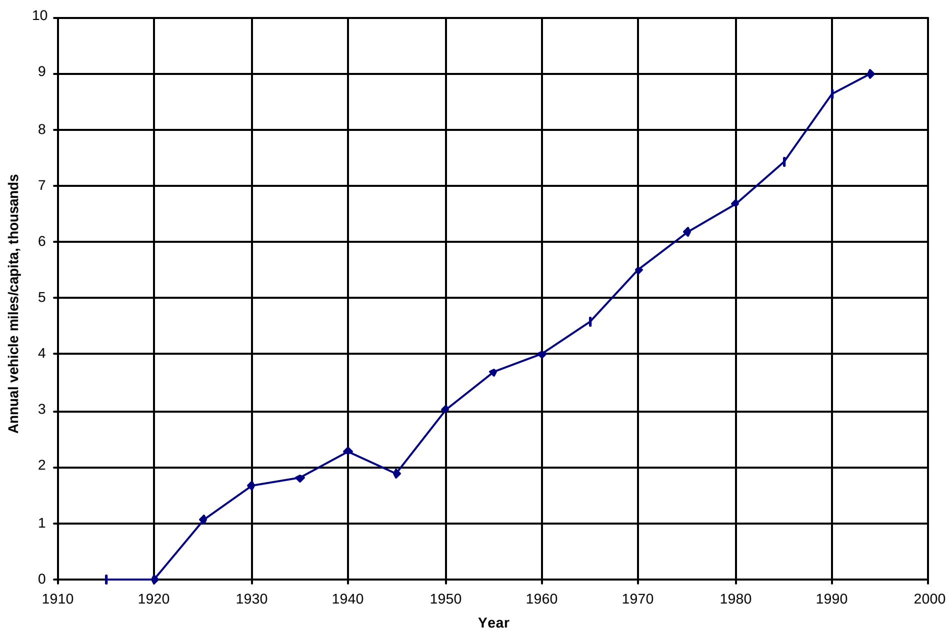

Figure 2-3. Trends in vehicle miles per capita in the U.S.

and gas taxes cover only about 9 to 18% of the cost of transportation (Kunstler 1996). Goldstein (1997) estimates that 25% or more of newly-developed land is committed to roads, parking, driveways, and garages.

The preceding discussion indicates the dominant impact of the automobile on contemporary urban settlements. In order to accommodate more cars and higher rates of utilization, the sizes and proportion of property devoted to vehicles has increased dramatically. One example is the shift from one to two and even three car garages. Parking and other support services have similarly expanded. A key question for the future is whether these trends will continue. If they do, then wet-weather problems will continue to grow in relative importance as will air pollution and noise problems.

Impact of Subdivision Regulations

Southworth and Ben-Joseph (1995) present an overview of suburbia evolution since 1820. They trace the evolution of the current design standards for suburbia, with particular emphasis on city streets. They bemoan the consequences of current standard practices stating (Southworth and Ben-Joseph 1995):

> ***Attempts to reshape the form of the American city are often thwarted by the standards and procedures that have become embedded in planning and development. Particularly troublesome are standards for streets that virtually dictate a dispersed, disconnected community pattern providing automobile access at the expense of other modes. The rigid framework of current street standards has resulted in uniform, unresponsive suburban environments.***

The current residential street design standards which are accepted virtually throughout the United States necessitate a large amount of impervious area per family which consists of wide streets, sidewalks, and driveways.

Contemporary Neighborhoods and Urban Sprawl

Urban areas in the United States are using land four to eight times faster than the growth in population. The New York metropolitan area's population increase over the past 25 years has been only 5%, but the developed land has increased by 61%, replacing nearly 25% of the region's forests and farmlands (Peirce 1994). Cities are spreading over the natural landscapes far faster than population increases or economic progress requires, while older urban districts with their valuable infrastructures are under used or abandoned (Barnett 1993).

In spite of an aggressive program to control urban sprawl and acquire greenways, Portland, OR has grown by nearly 25% since 1980 while expanding its urban area by only 1%. Without such management strategies, the Chicago area's population has grown only 4% in the past 20 years but expanded its urban land by 35%. Between

1960 and 1990, the population of the Baltimore metropolitan area increased by 33% but the amount of land in the region used for urban purposes grew fivefold-by 170% (Katz 1997).

The subdivision is the basic building block of current land use and each parcel within the subdivision is designed to maximize its own identity and privacy. According to Kunstler (1996), the reigning metaphor for the “good life” in the United States is: “... a modest dwelling all our own, isolated from the problems of other people.”

However, these properties tend to be much larger than would be suggested by the word “modest” because they attempt to provide a variety of traditional community functions within their individual boundaries such as parks (front and back yard), parking (garages and driveways), and recreation (swimming pools, play areas). Each of these units exists in isolation.

Zoning laws are the chief public instrument used to separate functions in contemporary urban communities. Building the equivalent of Main Street USA in modern America is virtually impossible. It would violate current zoning law provisions such as setbacks, parking requirements, and mixing of land uses. Each major land use function is separated from the others requiring motorized transportation (typically an automobile) to get from one area to another.

Urban sprawl has been a widely debated topic during the past 25 years as automobile-dominated urban transit has become pervasive. Real Estate Research Corporation (1974) analyzed the costs of sprawl for a variety of land use scenarios ranging from uniform low density development to high density, clustered developments. As part of the large on-going effort to protect Chesapeake Bay, the effect of sprawl on land use has been quantified and its implications discussed. This study defined sprawl as (Chesapeake Bay Foundation 1996):

- the haphazard scattering of homes and businesses across the landscape, beyond already developed areas, far from cities and towns.

- an ineffective use of the land, difficult to service with infrastructure and transportation, requiring extensive use of automobiles, and consuming large land areas (CH2M Hill 1993).

- Residential development at a density of less than three dwelling units per acre (CH2M Hill 1993).

Tetra Tech (1996) defines urban sprawl as:

> ***Current development patterns, where rural land is converted to urban uses more quickly than needed to house new residents and support new businesses, and***

> ***people become more dependent on automobiles. Sprawl defines patterns of urban growth which include large acreage of low-density residential development, rigid separation between residential and commercial uses, minimal support for non-motorized transportation methods, and a lack of integrated transportation and land use planning.***

The National Commission on the Environment (1993) criticizes contemporary urban land use pattern by stating:

> ***Meanwhile, sprawling housing developments, shopping centers, highways, and myriad other developments have proceeded virtually unfettered by any sense of respect for the environment and humankind's relation to it. As a result, pollution from non-point sources continues to grow and is increasingly difficult to control; biological diversity is destroyed as habitats are fragmented and eliminated; sprawl development blighted the landscape and precludes cost-effective and environmentally beneficial means of providing transportation and other services; and inner cities at the core of metropolitan areas increasingly are home to people who have been abandoned as hopeless by the rest of U.S. society.***

The impacts of sprawl in the Chesapeake Bay area include (Chesapeake Bay Foundation 1997):

1. Five to seven times the sediment and phosphorus as a forest.
2. Nearly twice as much sediment and nitrogen as compact development.
3. Each person uses four to five times as much land as 40 years ago.
4. Twice as much road building as compact development.
5. Three to four times as many automobile trips per day.
6. Much more air pollution as compact development.
7. Lower tax revenues than the cost of providing these services.
8. Induced relocation of people from central cities and inner suburbs.

Historical Infrastructure Development Patterns

Early infrastructure systems tended to be smaller in size with customers providing some or all of the necessary services or participating in smaller utilities to provide water supply, wastewater, and stormwater services as separate entities. Early transportation systems were often private toll roads. Citizens also formed cooperatives to share the cost of building and maintaining these roads.

The first major call for governmental participation in road construction came in the late

19th century in response to requests from the bicycle community to provide improved roads. Prior to the automobile, railroads provided much of the transportation infrastructure for trips of any significant distance.

Regionalization of urban wastewater infrastructure began in earnest in the 1960's and early 1970's with the federal government providing large subsidies for construction of new wastewater treatment plants and interceptor sewers. Under this program, the urban areas were required to demonstrate that the proposed system was the most cost-effective. Typically, the preferred solution was to build very large regional systems to serve the entire metropolitan area. From a regulatory viewpoint, the agencies strongly preferred larger regional systems since they were easier to administer as opposed to dealing with numerous individual cities and suburbs. The availability of federal subsidies in the range of 75% of the construction cost had a major influence on the decision that "bigger is better". Analogous central systems emerged in water supply, stormwater, and transportation.

Interceptor Sewers and Urban Sprawl

Binkley et al. (1975) evaluated the effect of federally subsidized construction of large interceptors on urban sprawl. The federal government paid 75% of the initial capital cost of interceptors to provide for the existing and future populations. They felt that this subsidy encouraged overdesigning the interceptor sewers. Excess capacity is paid by existing residents who derive little or even negative benefit from it. One alternative funding option is to subsidize only that portion of the interceptor that serves the existing population. Additional capacity would have to be paid by owners of the benefiting property.

This study analyzed 52 interceptor projects. The following conclusions were reached:

- About one half of the total federal investment benefited future growth, not existing customers.
- The costs of excess capacity averaged $145 per capita and was as high as $658 per capita, measured in 1975 dollars.
- Design project periods with a median of 50 years were used. It would be more efficient to use shorter periods of, say 25 years, to reduce uncertainty and to give the existing communities more control over future growth patterns.

Based on this evaluation, Binkley et al. (1975) make the following recommendations:

1. Provide no federal funds for excess capacity. Future growth should pay its own way. Subsidizing this growth will encourage sprawl. Reevaluate interceptor staging of project design in rapidly growing areas. Using shorter design periods reduces the tendency to subsidize future growth. Excess capacity does impose extra cost, especially if it is not used.
2. Use realistic standards for per capita flows. EPA recommended average sewage flows of 100 to 125 gpcd when actual flows average 40-60 gpcd.

3. Improve population forecasting techniques
4. Require consideration of environmental effects of interceptor-induced land use. Increase public participation in the project so that existing stakeholders better understand the environmental and financial implications of the projected project.

Federal Housing and Urban Development Programs

Federal government policies to promote urban economic development have evolved over the past 50 years. Following World War II, urban renewal programs aimed at building affordable housing flourished. The Clinton administration relies on the establishment of empowerment zones and enterprise communities (Moss 1997). These programs have focused on the bricks and mortar aspects of the problem. The Clinton administration's empowerment zone is modeled on the "enterprise zone" concept used in Britain where public investment is attracted by eliminating government regulations and taxes in the worst areas of the city (Moss 1997). According to Moss (1997), the migration of population from the cities to the suburbs is the result of numerous forces including racial and ethnic bias, the construction of high-speed expressways, crime, the decline of urban public schools, and the cultural appeal of low density, single-family housing.

Engel et al. (1996) discuss how the U.S. Dept. of Housing and Urban Development (HUD) and EPA are changing to better integrate their respective missions. They trace the origins of the environmental movement in the United States to late-19th century concerns about poor public health and sanitation conditions in cities and to the need to protect open space and wildlife in undeveloped areas. Early public interventions in housing were brought about by public health concerns about overcrowding, open spaces and urban parks, light and air, sanitary facilities, potable water, and housing and building codes (Engel et al. 1996). The Housing and Urban Development Act of 1968 was intended to have HUD take the lead in implementing a comprehensive urban strategy. The implementation of this act emphasized construction of housing.

Concurrently, major environmental initiatives came on line as a result of numerous legislative mandates. Interestingly, there was little interaction between housing and urban policy advocates and environmental organizations during the 1970s and 1980s and the two programs developed separately. In 1993, the New York Citizens Housing and Planning Council held a conference on housing and environment. Critics argued that environmental regulations were "...endangering the economic viability of the existing housing stock and the rehabilitation or new construction of low-and moderate-income housing." (Engel et al. 1996). This initial effort stimulated other workshops and the development of joint activities between EPA and HUD in areas of common interest such as brownfields.

Engel et al. (1996) synthesize the current situation into four categories arranged in ascending order of difficulty:

1. Procedural reforms: Concern exists that existing environmental regulations, particularly federal mandates, are unduly restrictive and cumbersome. They need to be made more flexible and better integrated into the local planning and permitting process.

2. Balancing of social goals: A natural tension exists between developers and regulators. Strong federal environmental regulation is intended to provide a check against too much control by local development interests. However, these regulations and associated liability have strongly discouraged redevelopment of older sections of urban areas by encouraging builders to go to new areas where environmental cleanup is not an issue. Unfortunately, this contributes to urban sprawl.

3. Urban risk analysis: The comparative risks of environmental stressors need to be prioritized based on the cost effectiveness of reducing these risks. Progress is being made in this area in that individual risk assessments are being done, such as use-based cleanup standards for brownfields. However, it is still difficult for local authorities to develop their own priorities on relative risks because environmental regulations are organized by individual media and pollutants. Trade-offs may not be permitted.

4. Allocation of costs: The issue of who pays for environmental cleanup is at the heart of current debates. During the 1970's, the federal government paid a large share of these control costs. However, this is no longer the case. As of 1990, the federal government was only paying about 30% of pollution control costs (Engel et al. 1996). A significant part of the residual cost falls on local residents, many of whom have limited ability to pay.

Federal Transportation Programs

The federal government has provided the bulk of the financing for the interstate systems that has had a major impact on urbanization since the late 1950's. This support has continued and has been a major inducement for promoting automobile use in urban areas (Littman 1998).

Summary of the Impacts of Federal Urban Programs

Beginning in the 1930's, federal programs to insure mortgages, and associated guidelines for "good" subdivision design, have resulted in widespread adoption of zoning and land use ordinances that foster lower density suburban development. Transportation agencies at all levels have promoted automobile use by providing large subsidies for this mode of transportation and mandating "free parking" and generous widths on little used streets. USEPA construction grants for wastewater treatment during the 1970's encouraged construction of large interceptor sewers and centralized wastewater treatment plants. The large amount of "excess capacity" in these systems encouraged low density development as cities sought customers to utilize this available capacity. Liability concerns with renovating brownfields in urban areas encouraged migration away from the core city to greenfield areas. Recent years have seen a rekindling of interest among federal agencies to look at urban systems in a more unified manner in order to promote more sustainable communities.

Possible New Approaches

Neo-traditional Neighborhoods

One attempt to develop modified urban land use patterns is called the New Urbanism school. New urbanism is also called neo-traditional planning, traditional neighborhood development, low density urbanism, or transit oriented development (Kunstler 1996). The key component of the "new approach" is to return to the pre World War II practice of designing urban neighborhoods with a mix of land uses rather than segregating land uses by function as currently exists. Features of traditional neighborhood developments (TND) include the following (Chellman 1997):

1. Mixed land uses.
2. Gridiron street pattern to maximize circulation. The goal is to maximize connectivity of streets, not the opposite.
3. Most TND streets are designed to minimize through traffic by using tee intersections.
4. Alleys.
5. Garages in rear of house facing alley.
6. Smaller front yard with porches to reflect the increased friendliness of neighborhood.
7. Higher densities that promote alternative forms of transportation to the automobile. Typical TND densities in the United States are 6-10 dwelling units per acre.
8. Designed to maximize non-motorist mobility for residents and visitors.
9. Residential streets are designed for shared use; they are not designed merely to optimize automobile movement. Examples of narrower streets in traditional neighborhoods include (Chellman 1997, p. 25) two lane-two parking lane streets with a 25 foot curb to curb dimension (Seattle, WA), 28 to 32 feet wide (Georgetown in Washington, D.C.), 21 feet wide (San Francisco, CA), 22 feet wide (Madison, WI), 26 to 30 feet wide (Portsmouth, NH), and 18 to 28 feet wide (Portland, OR). As Chellman (1997) points out, the narrower streets reduce traffic speeds to 10-20 mph, thus improving safety for other users.
10. The scale of the design is based on the primary user being a pedestrian, not an automobile driver. For example, signs are smaller.
11. TNDs are sized based on walkability. Thus, they range in size from 40 to 125 acres.
12. Most commercial units have residences located on upper floors of the TND project.
13. On-street parking is allowed.

A prominent example of a neo-traditional community is Celebration, a new development by Disney Corporation near Orlando, FL. This 4,900 acre development will house 20,000 residents in a mix of land uses. These new communities try to reduce the impact of the automobile on urban settlements. Smaller streets are used in the neighborhoods. Alleys with garages are used so that streets will be lined with front porches and lawns, not garage doors and driveways. Open space including pocket parks are an integral component of these new communities. Ben-Joseph (1995) presents several examples of such developments in the Netherlands, Germany, England, Australia, Japan, and Israel. Another example in the U.S. is Seaside, FL (Mohney and Easterling, eds. 1991).

The preceding examples of “new urbanism” reflect current attempts to convince Americans that alternative options exist. However, many long-term examples already exist in older cities of the United States and Europe.

Newsweek (1995), in an article based on interviews with leading New Urbanism proponents, Andres Duany, Elizabeth Plater-Zyberk, Peter Calthorpe, and Henry Turley, summarizes 15 basic tenets of the new urbanism:

1. Give up big lawns: they increase sprawl, require large amounts of irrigation water, and increase alienation.
2. Bring back the corner store: a simple development that both brings local residents together and a convenience that does not require a 10-mile trip to the supermarket.
3. Make the streets skinny: plan neighborhood streets for walking not driving.
4. Drop the cul-de-sac: although a “dead-end” neighborhood prevents through traffic, it chokes that one road that connects the neighborhood with the rest of the world.
5. Draw boundaries: limit the city’s physical size; don’t let population increase cause sprawl.
6. Hide the garage: neighborhoods are for living, not parking.
7. Mix housing types: avoid monoculture neighborhoods and invite diversity through development.
8. Plant trees curbside: beautify the places we travel and walk.
9. Put a new life into old malls: plan shopping centers not entirely around the consumer, but strive to bring together a community.
10. Plan for mass transit: encourage alternatives to the automobile.
11. Link work to home: break the idea that one has to travel a great distance to work.
12. Make a town center: focus a development around a public center
13. Shrink parking lots: business can share parking.
14. Turn down the lights: light streets for the pedestrian, not the automobile.
15. Think green: instead of endless manicured green carpets, invite nature into the community.

The wave of interest in New Urbanism concepts of urban planning has rekindled the debate regarding the pros and cons of traditional neighborhood developments. Chellman (1997) presents an overview of the debate and evaluates the transportation aspects of traditional neighborhood development. Ewing (1996) evaluates new urban developments and compares them to traditional developments. He presents a list of best development practices for land use, transportation, housing, and environmental practices. No work was found that evaluated the impact of neo-traditional development on urban water infrastructure. Accordingly, a preliminary evaluation of this topic is presented in this report.

Related EPA Activities Dealing with Urban Growth Patterns

In addition to the activities of the National Risk Management Research Laboratory that is sponsoring this study, other groups within US EPA are interested in issues of urban development and its environmental impacts. These groups are discussed here.

Green Development

U.S. EPA's Office of Wetlands, Oceans and Watersheds is developing the Green Development approach to make urban growth and development work with existing environmental resources. Tetra Tech (1996) compiled a list of case studies of innovative urban development. The case studies are divided into the following categories:

- Urbanizing suburbs and areas where infill has successfully occurred (See Table 2-2).

- Intermodal transport policies that consider environmental impact (See Table 2-3).

EPA's air quality control program is encouraging methods to reduce the demand for vehicle travel by a variety of means including charging systems (ICF Incorporated and Apogee Research Inc.1997).

Green development achieves its goals using the following (Tetra Tech 1996):

1. Flexible zoning and subdivision regulations.
2. Management of growth through agriculture and natural resources preservation.
3. Comprehensive and integrated site planning.
4. Reduction in site imperviousness.
5. Restoration of the site hydrologic regime to mimic the natural or predevelopment condition.
6. Maintenance of surface water and groundwater quality and minimization of the generation and off-site transport of pollutants.
7. Minimization of disturbance of riparian habitat functions.
8. Preservation of terrestrial habitat ecological functions and maximizing conservation of woodland and vegetative cover.
9. Use of compact, pedestrian-friendly development practices.

Studies of Chesapeake Bay

The Chesapeake Bay Foundation (1996) advocates the following principles to avoid sprawl:

1. Channel development into “growth areas,” that is, compact mixed-use patterns in and adjacent to existing cities and towns.
2. Create “growth boundaries” to keep sprawl out of open lands where farming, forestry and recreational activities should prevail.
3. Maintain existing highways, improve local roads, and use transit to connect and organize land uses in growth areas.
4. Revitalize existing towns and cities.

Table 2-2. Case studies on "urbanizing" suburbs and areas where infill has successfully occurred (Tetra Tech 1996).

Case Study Name	Location	Economic Analysis Included?
California Infill Development Program	California	No
Downtown Master Plan*	City of West Palm Beach, FL	No
Florida Main Street Program	State of Florida	No
Grand Central Square	Los Angeles, CA	Yes
Memorial Park	Richmond, CA	Yes
Mizner Park	Boca Raton, FL	Yes
River Place	Portland, OR	Yes
Uptown District	San Diego, Ca	Yes
Ballston	Arlington, VA	No
Main Street	Huntington Beach, CA	No
Downtown Redlands	Redlands, CA	No
Whittier Boulevard	East Los Angeles, CA	No
The Eastward Ho! Initiative	South Florida	No
Fearrington	Near Chapel Hill, NC	No
Fairview Village	Near Portland, OR	No
Downtown area	Mashpee, MI	No
Downtown area	Boca Raton, FL	No
Revitalization Plan	Orlando, FL	No
The Florida Avenue Project	Miami, FL	No
The Jordan Tract	Mount Pleasant, SC	No
North Boulder	Boulder, CO	No
South Martin County	Martin County, FL	No
Master Plan	Port Royal, SC	No
Montgomery Village	Montgomery Township, NJ	No
Lake Park Village	Union County, NC	No
Oak Ridges Moraine	Toronto, Canada	No
Peaks Branch	Dallas, TX	No
Dorsey Woods	Arlington, VA	Yes

Brownfield Redevelopment

The US EPA is promoting the redevelopment of brownfields in older urban areas. A review of this program highlights many of the challenges of reversing the trend from continued development of green fields on the periphery of urban areas to redevelopment of existing areas. Challenges include technical, socio-economic, and liability issues as discussed below. Barnette (1995) lists three advantages of redeveloping brownfields:

- Brownfields are properly zoned and thus well suited for industrial and commercial use.
- The civil infrastructure and utilities necessary for industrial operations are already in place at many brownfield sites.
- Brownfield redevelopment preserves the nation's virgin land and natural resources.

Table 2-3. Case studies using intermodal transportation policies that consider environmental impacts (Tetra Tech 1996).

Case Study Name	Location	Modes Provided ($)[1]
Effects of Interstate 95 on Breeding Birds	Maine	A
For Animals. It's the Road to Safety	Washington, DC	A
Haymount	Caroline, Co., VA	T,A
Skinny-Streets & One-sided Sidewalks: A Strategy…Paradise	Olympia, WA	A
I-287 it and They Will Drive On It	Wanaque, NJ	A($)
For Many, Gas Guzzler is Necessary Tool, Not a Toy	Cllifton Park, NY	A($)
The Road Less Noisy: How America is Muffling the Highways	Colorado	A($)
Portland's Pedestrian Master Plan	Portland, OR	P
City of Toronto	Toronto, Canada	T,A
City of Seattle Bicycle Program	Seattle, WA	B
State of Washington Transportation Planning	Washington	T,A,P
Core Area Requirements to Support Non-Auto Trips, New Jersey Transit	New Jersey	T,A,P
Designing for Transit, Integrating Public Transportation and Land Development	San Diego Metropolitan Area	T,A,P
Guide to Land Use and Public Transportation	Snohomish County, WA	T
The Citizen Transportation Plan for Northeastern Illinois	Chicago Region, IL	T,A($)
Transit-Supportive Land Use Planning Guidelines*	Ontario, Canada	T,A,P
TCEA-Transportation Concurrency Exception Area	Delray Beach, FL	T,A,P,B
Smart Development Program	State of Oregon	T,A($)
The Crossings	Mountain View, CA	T,A,P($)
Old Pasadena	Pasadena, CA	T,A,P
North Thurston UGMA	Thurston County, WA	T,A,P
North Boulder	Boulder, CO	T,A
South Martin County	Martin County, FL	T,A,P
Revegetation along US 189	Provo Canyon, UT	T
Stream Restoration in Boulder	Colorado	P,B
Rail Plan on the Wrong Track	Maryland	T($)
MSHA Grown, Don't Mow Program	Maryland	T

1) A: Auto, B: Bicycle, P: Pedestrian, T: Transit, $: Economic analysis included.

Collatin and Bartsch (1996) discuss three major concerns regarding brownfield redevelopment: the high cost of cleanup, the uncertainty about liability and procedures, and a negative public attitude towards old facilities. Cleanup costs are an upfront cost for developers and include required site environmental assessments for all properties. Given the initial assessment, the developer still faces major uncertainties about the ultimate final cost. Thus, lending institutions are understandably reluctant to become involved in such high-risk ventures. Review procedures are complicated by not having clear guidelines on the required level of control and the extent of the public review process. Lastly, the above concerns and a recent history of negative attitudes towards these properties further reduces their desirability. Amedudzi et al. (1997) provide an overview of brownfield redevelopment issues at the federal, state, and local levels.

The follow existing brownfield demonstration projects are explicitly linked to urban water systems (Colatin and Bartsch 1996):

1. Birmingham, AL: Link environmental protection approaches involving flood control and stormwater/groundwater contamination reduction with remediation of soil and site-specific contamination, and develop consortium of community leaders to direct resources to targeted areas.

2. Erie County, NY: Brownfield cleanup as part of a large waterfront redevelopment project.

3. Laredo, TX: Seek conversion of brownfield into waterfront recreation area near campus of a community college.

4. Lima, OH: Focus on remediating and redeveloping 200-acre industrial park and support ongoing river corridor redevelopment activities in order to enhance water quality and provide greenspace.

5. Pritchard, AL: Remediate extensive organic chemical contamination of city's water supply by using State Enterprise Zone tax credits to encourage investment.

Sustainability Principles for Urban Infrastructure

A general guiding principle for designing innovative urban stormwater management systems for the 21st century is that they promote sustainable development. A popular general definition of sustainable development is:

> ***Development that meets the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development 1987).***

The following principles are suggested for sustainable infrastructure systems for the 21st century:

1. Ideally, individual urban activities should minimize the external inputs to support their activities at the parcel level: For water supply, import only essential water for high valued uses such as drinking water, cooking, showers and baths. Reuse wastewater and stormwater for less important uses such as lawn watering and toilet flushing. Minimize the demand for water by utilizing less water intensive technologies where possible. For transportation, minimize the generation of impervious areas, especially directly connected impervious areas, for providing traffic flow and parking in low use areas.

2. Minimize the external export of residuals from individual parcels and local neighborhoods: For wastewater, export only highly concentrated wastes that need to be treated off-site. Reuse less contaminated wastes such as shower water for lawn watering. For storm water, minimize off-site discharge by encouraging infiltration of less contaminated stormwater and using cisterns or other collection devices to capture and reuse stormwater for lawn watering and toilet flushing.

3. Structure the economic evaluation of infrastructure options to maximize the incentive to manage demand by using commodity use charges instead of fixed charges: For water supply, assess charges based on the cost of service with emphasis on commodity charges. Charges should be a combination of a level of service that specifies flow, quality, and pressure. For wastewater, assess charges based on the cost of service with emphasis on commodity charges. Charges should be a combination of a level of service that specifies flow and quality. For stormwater, assess charges based on the cost of providing stormwater quality control for smaller storms and flood control for larger storms. Charges should be based on the imperviousness with higher charges for directly connected imperviousness and the nature of the use of the impervious areas and their pollutant potential. Some charge should be assessed for pervious areas. Credit should be given for on-site storage and infiltration. For transportation, assess charges for transportation related imperviousness directly to users as fees per mile for travel and fees per hour for parking in order to encourage demand management and switch to more sustainable modes of transportation.

4. Assess new development for the full cost of providing the infrastructure that it demands, not only within the development, but also external support services.

5. Implement policies to make drivers pay the full cost of using personal automobiles.

The following list of other goals provides additional criteria for more sustainable new communities. These topics overlap and can be consolidated down to a much smaller set of principles.

1. Re-develop vacant or low-density development within currently developed areas at higher intensities.
2. Design comprehensive, mixed-use neighborhoods instead of isolated pods, subdivisions and developments. The spaces between neighborhoods should consist of functional open space such as farms, grazing areas, gardens, parks, playgrounds, bikeways, jogging trails and the like.
3. Encourage telecommuting and the infrastructure necessary to make it work.
4. Do a comprehensive accounting of infrastructure costs that reflects social and environmental costs as well as economic costs. Current investments based on partial and incomplete accounting systems are considered to be factors in urban sprawl and the inability of infrastructure capacity to keep pace with these urban development patterns.
5. Develop a community designed for people first, that does not damage the natural environment, that enables a healthy, active lifestyle, where human interaction is an everyday event (Goldstein 1997).
6. Housing, stores, and employment will be accessible (less than 20 minutes) to each other by walking, biking and transit (Goldstein 1997):
7. With regard to environmental impacts, the City of Dreams will have the following benefits (Goldstein 1997):
   a. Reduce energy demand by 75%.
   b. Reduce water use by 65%.
   c. Reduce solid waste by 90%.
   d. Reduce air pollution by 40%.

Much general information on this subject is available on the internet, (e.g., see $mart Growth Network-www.smartgrowth.org).

Sustainability and Optimal Size of Infrastructure Systems

While the notion that "bigger is better" still persists, some argue that these systems are not sustainable. Problems with larger systems include:

1. Large organizations are necessary to manage these systems.
2. Large organizations with monopoly powers tend to be inefficient and less responsive to changing needs.
3. Complex cost sharing arrangements need to be developed to fairly charge each group for its share of the cost of the system.
4. Complex political institutions are needed to govern these systems that cross city, county, and even state boundaries.
5. Part of the savings associated with regional systems results from transferring problems from area to area so as to take better advantage of the assimilative capacity of the receiving environment. While such solutions may reduce

costs overall, they may be highly objectionable to citizens in those parts of the service area that receive a disproportionate share of the negative effects of such transfers, (e.g., added flood hazard , traffic noise, more polluted water).

6. Large regional systems are inefficient if recycling of treated wastewater and stormwater is desired since it is necessary to pipe and pump this water back through the entire system.
7. The failure of larger systems causes more serious consequences since larger areas are affected and illicit discharges are concentrated at fewer points.
8. Customers are less aware of the nature of the problems that they cause and are therefore less receptive to their responsibility to better manage their demand for the service.
9. The strong tendency for urban sprawl that has accompanied the creation of these regional systems makes them even less efficient due to the added distribution costs associated with more dispersed development.
10. It is necessary to build large amounts of excess capacity into these regional systems. Thus, the existing customers pay this added cost. The primary beneficiaries of this largesse are new customers. Correspondingly, the governing agency has a strong incentive to promote the growth of the area to help pay for this unused capacity.
11. Regional systems serve a heterogeneous group of customers including domestic, commercial, and industrial users. Thus, the nature of the wastes are harder to predict and the design must be upgraded accordingly. The use of a regional system encourages off-site discharge of wastes instead of prevention or treatment at the source.
12. Once established, it is difficult to restructure large organizations who enjoy monopoly power to provide the infrastructure service.

Given the above concerns, one of the main themes of this report is the need to rethink this basic “bigger is better” premise that has guided water infrastructure development during the past 30 years. Perhaps, bigger is not better.

Models for Evaluating Future Infrastructure

Beginning in the 1960’s, large-scale efforts were made to develop urban planning models that link land use, transportation, and infrastructure including environmental impacts. Large simulation models were developed to support these efforts. These models included the critical interaction between provision of infrastructure and land use. This is particularly important in showing the impact of transportation on land use. These early models were severely limited due to use of relatively primitive computers, lack of good databases, and poor knowledge of the underlying cause-effect linkages of urban dynamics (Lee 1973). Few urban models were developed after the early 1970's but a renaissance in the development and use of these models began to occur in the early 1990s (Wegener 1994). The resurgence of interest in urban planning models in the 1990's is partially due to the renewed recognition of the need to link transportation-land use models to urban environmental systems models.

Integrated urban models to evaluate the overall efficacy of alternative growth scenarios do not exist. However, there are individual models for water, wastewater, stormwater, and transportation. These models need to be integrated with each other and with land use models at both the micro (neighborhood) scale as well as the macro (urban area) scale. Preliminary evaluations using simple models are presented in this report.

Research Initiatives Related to Urban Infrastructure

Until recently, research support has been unavailable for evaluating alternative infrastructure systems. However, the National Science Foundation has initiated research programs in this area. Zimmerman and Sparrow (1997) summarize the results of an NSF sponsored workshop on integrated research for civil infrastructure. This is the third workshop on this subject since 1993. The participants strongly recommended a holistic view of infrastructure development. Sustainable infrastructure is defined as: "Achieving a balance of human activity (including human settlements and population growth) with its surroundings, so as not to exceed available resources."

Infrastructure sustainability is discussed around four topics:

1. Life-cycle engineering (LCE), that is, a process that incorporates into design the "true costs" of construction, operation, maintenance, renewal, and any other requirements over the expected lifetime of the facility. LCE includes design, construction, and repair, rehabilitation, reconstruction, retirement, and removal. Current costing methods and related institutions hamper LCE in the following ways:
    a. Incentives and statutory restrictions often favor "least-first-cost" contracting.
    b. New capital projects are often favored politically over maintenance or rebuild contracting.
    c. Tight budgets preclude field inspections, favor corrective over preventive maintenance, and encourage the use of minimal specifications for materials and structures.

2. Technology investment
    a. Mechanisms are needed to integrate infrastructure design, construction and maintenance. For example, integrated utility corridors provide a way to reduce the life cycle cost of infrastructure, particularly maintenance of subsurface infrastructure.
    b. Innovative approaches for technology investment at every point in the life cycle of infrastructure systems, (e.g. develop more durable materials, better monitoring and diagnostic techniques, better designs, and more rational methods for determining design safety factors throughout the lifetime of the infrastructure).

3. Performance measures
    a. Research is needed on the appropriate adaptation of process control management procedures in conjunction with advanced probabilistic and reliability methods for urban infrastructure systems.
    b. Research is needed on proper output performance measures for infrastructure and how it relates to costs.
    c. Performance measures need to be supported by direct monitoring of the physical state of the system and changing public expectations for use, capacity, and performance.

4. Project management
    a. A new generation of simulation and optimization models are needed to address both the new "intelligent" infrastructure, new model characteristics, and new cultures of the consumers.
    b. Encourage Design-Build-Operate (DBO) contracting mechanisms that will promote the evaluation of projects on a life-cycle basis. At present, using least cost criteria for design and construction leads to much higher maintenance costs over the life of the project. If the designer and builder also has to operate the infrastructure, they will have the proper incentives to minimize the entire life cycle cost, and not just the initial cost. Such procedures are already being used in Europe and Japan.

Transportation/Land Use Strategies to Alleviate Congestion
Congestion in urban transportation systems can be alleviated by expanding the capacity of the existing system. The capacity of the existing system can be expanded by improved traffic engineering and rescheduling work hours. also, demand can be managed by providing added incentives to use alternative modes of transportation, managing parking availability, promoting more transportation efficient land use patterns, and/or encouraging trip reduction through telecommuting or work at home options (Deakin,1995).

Projected Future Trends
Projected general trends are:

1. Continuing migration of population to cities throughout the world. By the year 2000, more than half of the world's population will live in cities. These cities will continue to grow in size with numerous mega-cities developing throughout the world. Okun (1991) summarizes the migration of people to urban areas around the world. In 1950, less than 30% of the world's population lived in cities. This percentage will exceed 50% by the year 2000. In developed countries such as the U.S., over 75% of the people live in cities.
2. The spatial settlement patterns of future urban development may differ significantly from current patterns. Population is being redistributed away from the core of the cities. Modern telecommunications could have a

profound impact on settlement patterns and transportation needs.

3. Public expectations about levels and types of service are continually changing as standards of living and life styles change.
4. The magnitude and distribution of investments in infrastructure are changing. Government subsidies of infrastructure are decreasing in some areas, (e.g., wastewater treatment plants), and increasing in other areas, (e.g., major highways and interstate expressways). The timing and lengths of budgetary cycles are changing with efforts to better integrate life cycle costs into new design and construction.

Origins of Stormwater in Urban Areas

Introduction

The purpose of this section is to evaluate the nature of the quantity of stormwater runoff in urban areas and to evaluate the relative importance of various sources. Water quality impacts are evaluated in Chapter 5.

Stormwater falls onto pervious or impervious areas. Runoff occurs after the infiltration capacity has been exceeded. Impervious areas have a very small amount of initial storage capacity whereas pervious areas have much larger initial storage capacities depending on the soil type and antecedent conditions.

A primary goal of sustainable water infrastructure systems is to maximize the management of the problem at the source, that is, the parcel or local level. Thus, it is important to understand the movement of water at this scale. An evaluation of the nature of the rainfall-runoff relationship at the neighborhood level is presented in the next section. Then, detailed discussions of the nature of impervious and pervious areas are presented in the later sections.

Rainfall-Runoff Relationships at the Neighborhood Scale

An integrated urban stormwater management program should provide a sustainable solution to the problem of handling storms of all sizes from micro-storms to major floods. Early studies in Chicago showed that most of the annual volume of runoff is associated with smaller storms as indicated in Table 2-4 (APWA 1968). For this Chicago catchment, 10.8 inches of runoff resulted from 34.7 inches of precipitation that occurred during 122 events. About 50% of the runoff resulted from precipitation of 0.5 inches or less, that roughly corresponds to storms that occur, once a month, on the average. Nearly 75% of the runoff volume is from storms that result from precipitation of one inch or less. Thus, the key point is that these smaller storms account for the majority of the runoff volume. Similar results were reported later by Heaney et al. (1977) and Roesner et al. (1991).

Early studies in Chicago by Harza Engineering and Bauer Engineering (1966) demonstrated that runoff is a nonlinear function of precipitation as shown in Figure 2-4. Up to rainfalls of two inches with corresponding runoff of about 0.6 inches, the relationship is linear with contributions only from the impervious areas, approximately an equal mix of runoff from directly connected roofs and streets and alleys. For rainfalls greater than two inches, runoff from pervious areas begins and becomes the major source for rainfalls greater than four inches.

Pitt and Voorhees (1994) show the nature of runoff for a residential area in Milwaukee as shown in Figure 2-5. For this case study, all of the runoff came from streets, driveways, and roofs up to precipitation depths of 0.1 inches. In this range, about 80% of the runoff came from transportation related imperviousness. As the rainfall depths increase, the landscaped areas become more significant sources of total runoff. At the one inch depth, landscaped areas contribute about 40% of the runoff.

These relative contributions are site specific but it is safe to conclude that the initial runoff is the runoff from the directly connected impervious areas. Impervious area (IA) is defined as land area that infiltrates less than 2% of precipitation that falls onto its surface directly or runs onto this surface. Directly connected impervious area (DCIA) is the IA that drains directly to the storm drainage system.

Table 2-4: Types of storms contributing to stormwater runoff in Chicago,IL (APWA 1968).

Precipitation (inches)	Average Runoff (inches)	Events per year	Precipitation (inches/yr.)	Runoff (inches/yr.)	% of Runoff	Cumulative % of Runoff
0.1	0.03	78.00	7.80	2.34	21.6	21.6
0.3	0.09	19.80	5.94	1.78	16.4	38.0
0.5	0.15	9.60	4.80	1.44	13.3	51.3
0.7	0.21	5.20	3.64	1.09	10.1	61.4
0.9	0.28	3.20	2.88	0.90	8.3	69.7
1.1	0.35	2.40	2.64	0.84	7.8	77.4
1.3	0.42	1.30	1.69	0.55	5.0	82.4
1.5	0.49	0.92	1.38	0.45	4.2	86.6
1.7	0.56	0.53	0.90	0.30	2.7	89.3
1.9	0.63	0.36	0.68	0.23	2.1	91.4
2.1	0.7	0.22	0.46	0.15	1.4	92.9
2.3	0.76	0.14	0.32	0.11	1.0	93.8
3.0	1.26	0.53	1.59	0.67	6.2	100.0
Total		122.20	34.73	10.84		

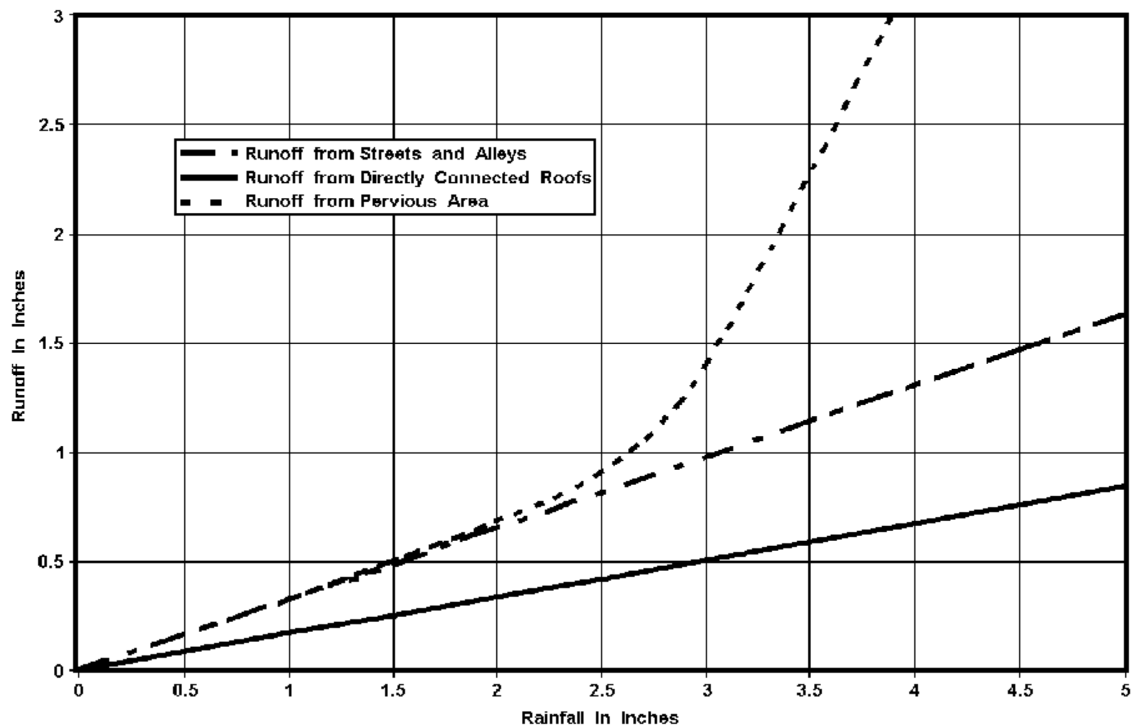

Figure 2-4. Rainfall-runoff relationships for unit area, Chicago,IL (Harza and Bauer, 1966).

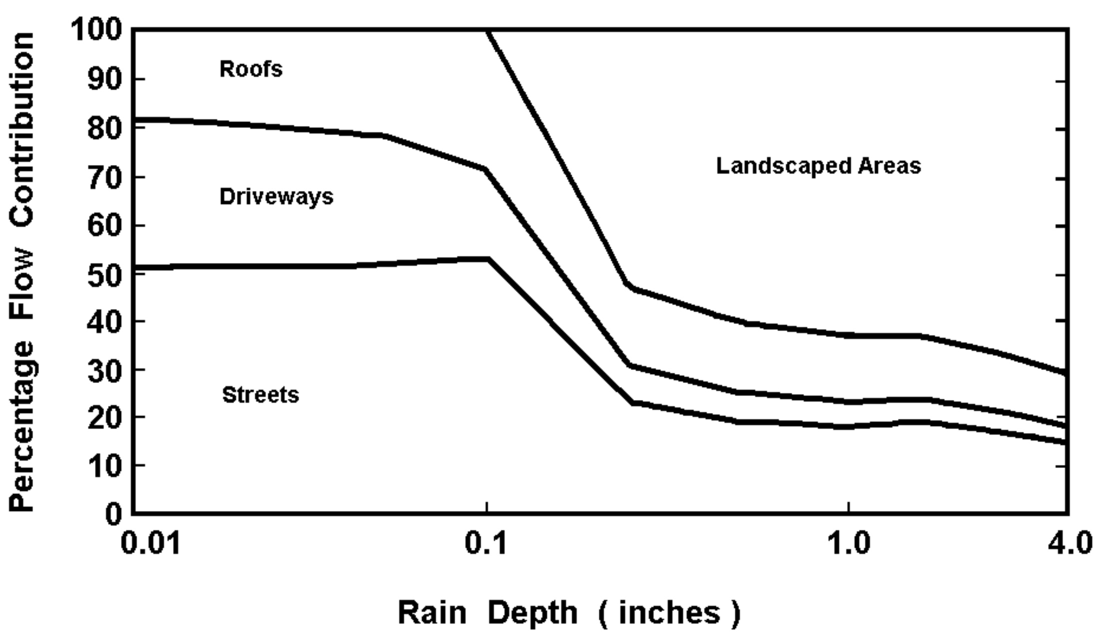

Figure 2-5. Flow sources for example medium density residential areas having clayey soils, Milwaukee, WI (Pitt and Voorhees, 1994).

Imperviousness has been suggested as a good single indicator of the extent of urbanization as far as stormwater impacts are concerned (WEF-ASCE 1998). For example, Schueler (1994) shows the dependence of the runoff coefficient on imperviousness. This relationship is based on evaluation of more than 40 runoff monitoring sites as part of the Nationwide Urban Runoff Program (NURP) studies. While a generally positive trend is evident in Figure 2-7, a large variability remains indicating that imperviousness alone is not an adequate predictor of runoff.

Population density has been used to predict imperviousness as shown in Figure 2-8 (Heaney et al. 1977). A primary unresolved source of variability in these results is the use of different bases for defining the service area. Some of these studies used small areas on the scale of blocks while others used aggregate data for much larger areas that included other land uses such as schools, parks, and commercial areas. Thus, the results vary widely.

Previous Studies of Imperviousness

Schueler (1996) cites the results of a recent study by the city of Olympia, WA which shows the components of imperviousness for a variety of land uses as shown in Table 2-5. Road related imperviousness is seen to comprise 63% to 70% of the total. Schueler (1995) contends that cluster development can reduce the imperviousness by 10-50% depending on the lot size and road network. Arnold and Gibbons (1996) show an example of the effect of cluster development in reducing imperviousness from 17.5% to 10.7%. Schueler (1995) presents a detailed analysis of the relationship between land use and imperviousness. He discusses alternative street designs, parking provisions, expected imperviousness, pollutant loads, and BMP options for control.

Debo and Reese (1995) show how to adjust SCS curve numbers based on the proportion of imperviousness that is directly connected. Unit pollutant loadings are often expressed in terms of curb lengths. Novotny and Olem (1994) show a relationship between percent imperviousness and curb length per unit area. The American Public Works Association (1968) estimated curb length as a function of population density. The use of population density as the independent variable is subject to significant error because it can be defined in several ways. The density varies significantly depending upon whether open space or other land uses such as streets are included in the area.

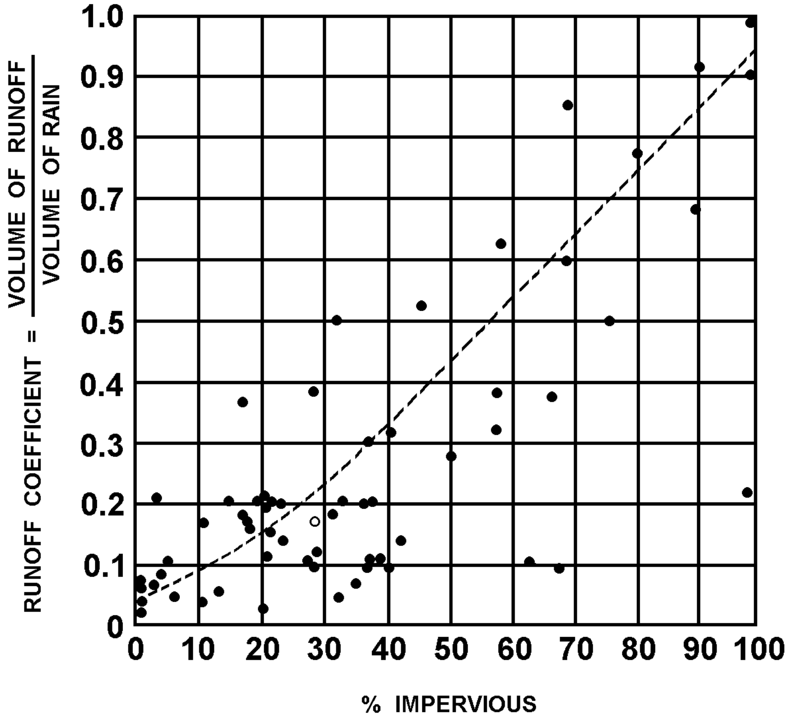

Figure 2-6. Relation of the coefficient of runoff for urban areas to imperviousness (Schueler 1994).

Table 2-5. Site coverage for three land uses in Olympia, WA (Schueler 1996).

	Average Approximate Site Coverage, %		
Surface Coverage Type	**High Density Residential (3-7 units/acre)**	**Multifamily (7-30 units/acre)**	**Commercial**
1. Streets	16	11	3
2. Sidewalks	3	5	4
3. Parking/driveways	6	15	53
4. Roofs	15	17	26
5. Lawns/landscaping	54	19	13
6. Open space	n/a	34	n/a
Total impervious surface (1-4)	40	48	60
Road-related impervious surface (1-3)	25	31	86
(Road-related as a percentage of total impervious coverage)	(63%)	(65%)	(70%)

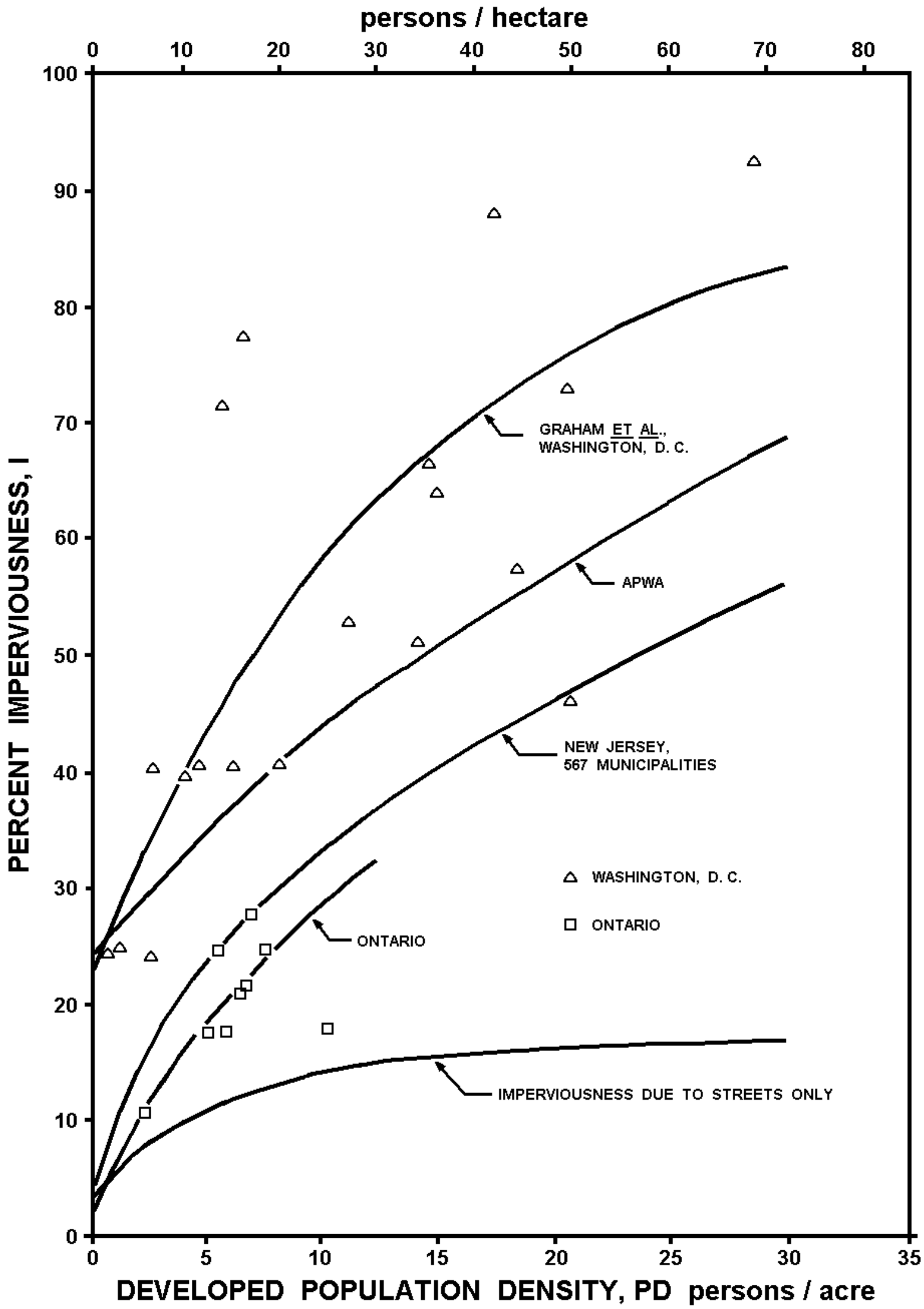

Figure 2-7. Imperviousness as a function of developed population density (Heaney et al. 1977).

Sources of Urban Runoff

A sketch of a contemporary residential lot and associated right of way (ROW) is shown in Figure 2-8. Each parcel consists of the development on the lot itself plus the adjacent development in the right of way that provides infrastructure services for this parcel, plus services for adjacent parcels. For this illustration, the overall area of the lot plus the ROW is summarized below:

Overall lot plus ROW area, sq. ft. =	7,020
Lot area, sq. ft. =	4,980
ROW area, sq. ft. =	2,040

For this case, about 71% of the total area is devoted to the lot and the ROW occupies the remaining 29%. This is close to a rule of thumb that says that the ROW occupies about 25% of the developable land area. When calculating development densities, it is important to define whether the denominator is the lot area only, the lot plus ROW area, or lot plus ROW plus other land uses including open space.

The percent imperviousness for the lot and ROW is 50.4% while it is only 38.2% for the lot only. The most dramatic statistic is the breakdown of imperviousness by function. Only 34% of the imperviousness is due to the living area itself. Nearly 60% of the imperviousness is due to providing for vehicles. The remaining 7% of the imperviousness is due to sidewalks.

The directly connected imperviousness (DCIA) is the most important component as far as causing stormwater runoff quantity and quality problems. About 80% of the DCIA is due to vehicle related imperviousness, predominantly the street and the portion of the driveway that drains to the street. While this percentage will vary, this illustration does indicate the dominance of vehicle related DCIA in contemporary urban development. It is now standard practice to discharge roof runoff onto pervious areas, particularly in lower density developments with well drained soils. Thus, rooftops are no longer the predominant source of DCIA; rather streets and driveways have grown in relative importance as the number of vehicles has increased. It is instructive to examine a cross section of residential land use to generate a database from which more general inferences can be made regarding how imperviousness is affected by land use.

Categories of Urban Catchments

A popular way to classify urban land uses is to define various categories of residential land use, (e.g., low density, commercial, industrial, and public land uses). Associated with each land use is an estimated imperviousness. A limitation of such general measures is that they don’t provide a breakdown on the nature of the imperviousness. Another limitation is lack of specificity in how the area is defined as discussed above. A

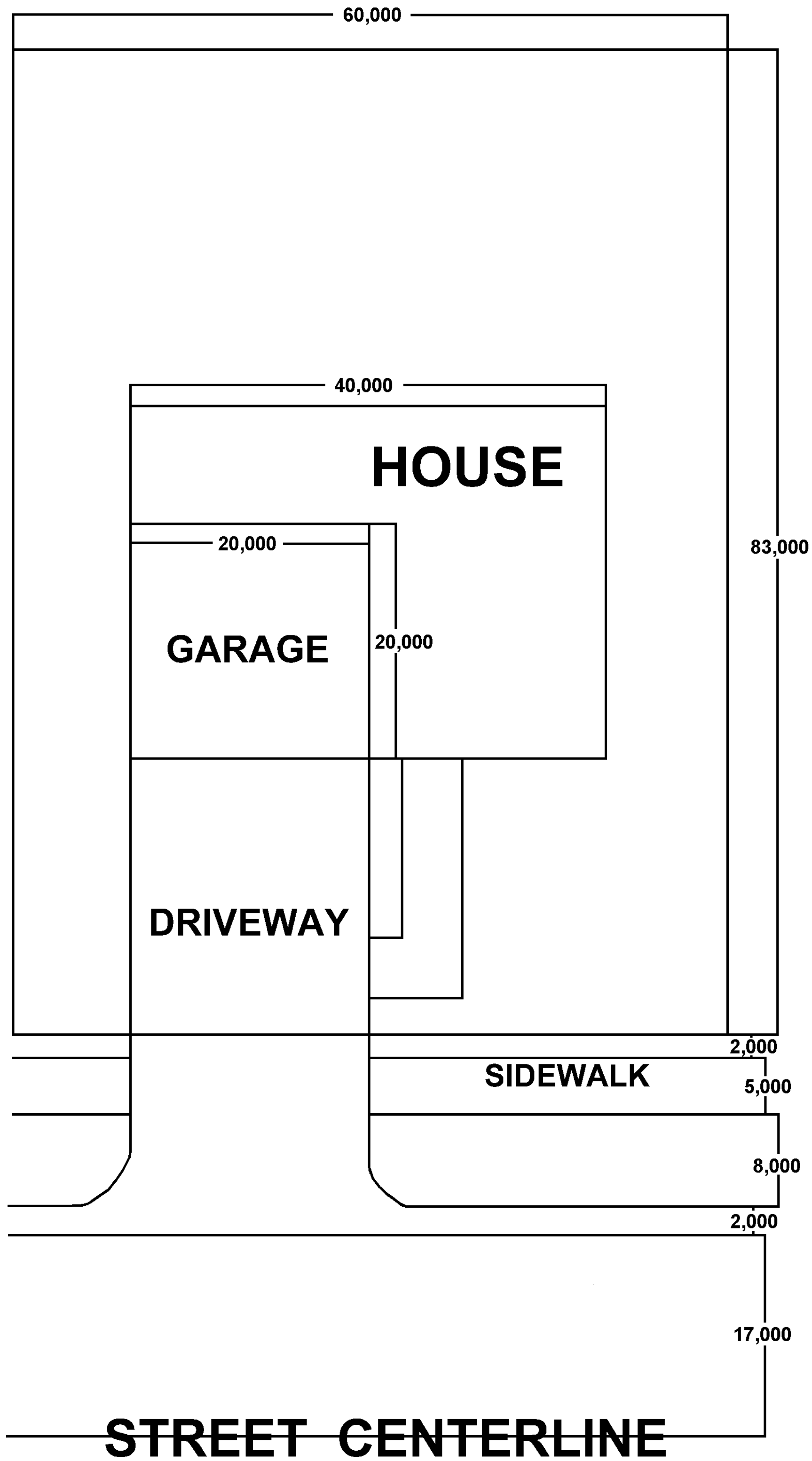

Figure 2-8. Example urban lot.

more functional way to partition urban areas is by the nature of the imperviousness and whether it is directly connected to the storm drainage system. For residential areas, the total land area can be divided into two major components: residential lots, and right-of-way, as shown in Figure 2-8. The lot portion of the area is divided into the following components:

1. House
2. Garage
3. Part of driveway
4. Yard
5. Walkway to dwelling unit
6. Pool
7. Deck/shed

The ROW portion of the area is divided into the following components:

1. One half of street consisting of driving and parking lanes
2. Curb and gutter, part of which is used as part of the parking lane
3. Pervious area between curb and sidewalk
4. Sidewalk
5. Pervious area between sidewalk and property line.
6. One half of an alley in some neighborhoods
7. Part of driveway

How Imperviousness Varies for Different Types of Urban Developments
Neighborhoods are the heart of urban development and the objective is to develop sustainable neighborhoods. Commercial, industrial and public areas can be part of the neighborhood or separate entities. For the purposes of this discussion, three categories of 20th century neighborhoods are defined: pre-automobile, pre-expressway automobile, and post-expressway automobile. The general attributes of these categories are shown in Table 2-6.

Pre-automobile neighborhoods were laid out and developed prior to 1920 and did not include accommodation of the automobile as an important design factor. With automobile use becoming significant in urban areas during the period from the 1920's to 1950's, the federal government encouraged the development of suburban type subdivisions with driveways and garages. The massive federally supported urban expressway program began in the late 1950s and now affects virtually every major community in the United States. The availability of expressways and the provision of "free" parking at destination points greatly accelerated the trend towards individual automobile travel in cities and surrounding areas. The term "automobile" is used to cover all categories of personal motor vehicles.

Table 2-6. Attributes of 20th century neighborhoods in the U.S.

	Pre-Automobile	Pre-expressway	Post-expressway
Neighborhoods			
Population Density	High	Medium	Low
Street Connectivity	High	Medium	Low
Alleys	Typical	Rarer	Very rare
Driveways	Rare	Some	Typical
Parking	On-street	On and off street	Mainly off-street
Dwelling Unit Size	Smaller	Medium	Larger
Garages	No	One car	Two-three car
Cars/dwelling unit	0	1	1-4
People/dwelling unit	4-5	3-4	2-3
VMT/cap-year	Negligible	2,000-3,000	8,000-10,000
Sidewalks	Yes	Yes	Yes
Type of sewer system	Combined	Mixed	Separate
Pervious areas/dwelling unit	Low	Medium	High
Land uses	Mixed	Hybrid	Separated
Covered porches	Very popular	Less popular	Less popular
Patios	Rare	More popular	Very popular
Commercial	Neighborhood/ Strip	Strip development	Shopping Center
Industrial	Neighborhood/ Separate	Neighborhood/ Separate	Separate

Pre-Automobile Neighborhoods

The approach taken is to evaluate a variety of residential land use patterns at the block or subdivision level and to vary the housing density for these units in order to calculate how directly connected (DCIA) and other (OIA) imperviousness varies as land use changes. A standard gridiron block with data from Chicago, IL and Boulder, CO is used. Two standard Chicago blocks are shown in Figure 2-10 (APWA 1968). This five acre block contains 36 houses (popularly called bungalows in Chicago) within the five acre block or an overall average density of 7.2 dwelling units per gross acre. Because of the high density and soils with limited infiltration capacity, the downspouts from the rooftops are connected directly to the sewers. The total imperviousness is about 57%. The DCIA is about 40% with the houses contributing about one half of the DCIA.

Land use in an older neighborhood in Boulder, CO is shown in Figure 2-10. The block size is identical to the Chicago blocks, (i.e., five acres in area) with a length of 660 feet and a width of 330 feet. However, unlike the homogeneous lot and house sizes in Chicago, the Boulder lots and houses vary widely in size and shape. The alleys in Boulder are semi-improved.

A spreadsheet was set up to estimate the nature of the imperviousness for these traditional gridiron street patterns. Six different housing densities are placed on these five acre blocks ranging from a high of 14.2 to a low of 2.4 dwelling units per gross acre. All lot sizes are identical within a given category. The results are shown in Tables 2-7 for total imperviousness and 2-8 for directly connected imperviousness.

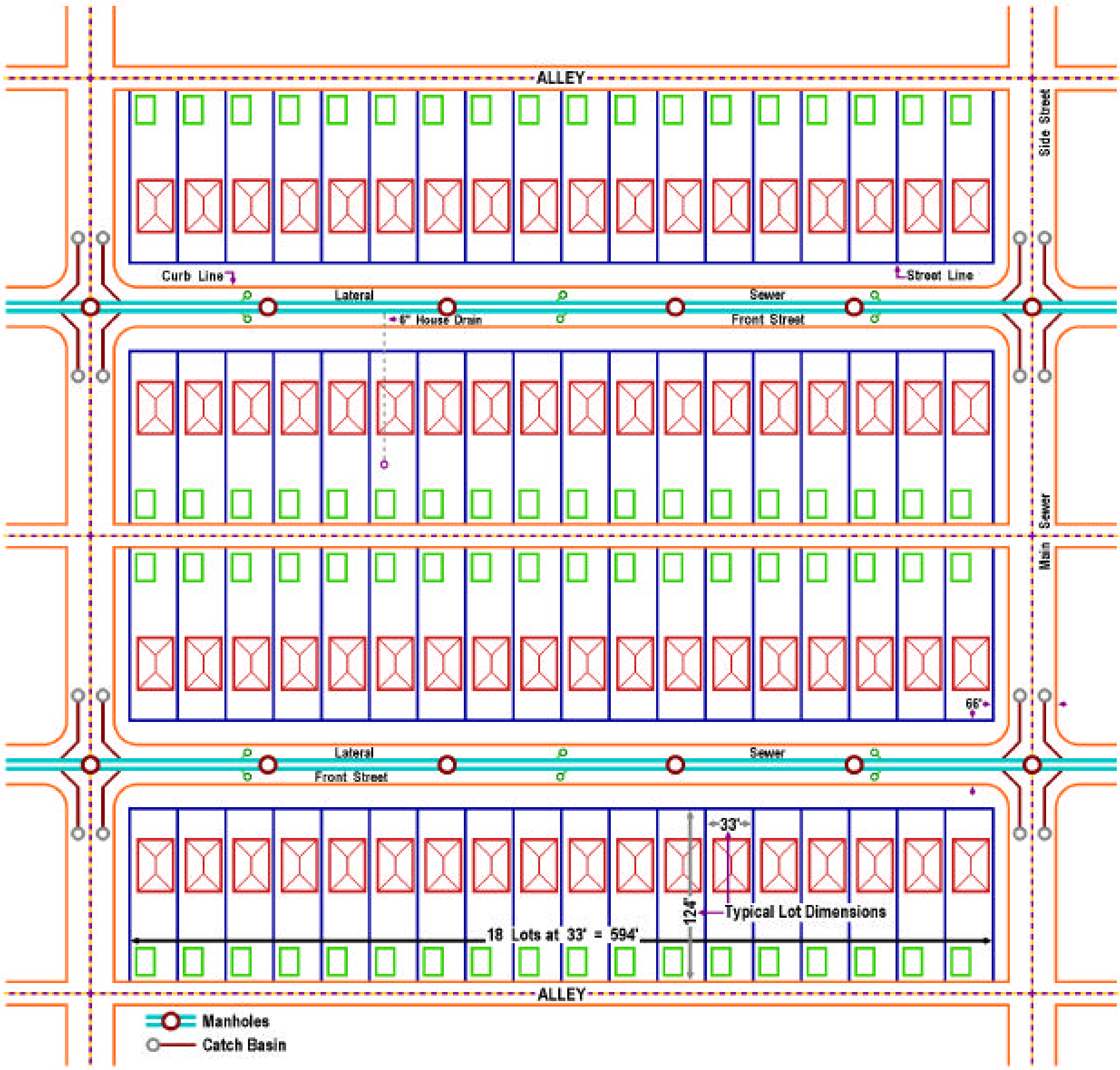

Figure 2-9. Typical unit residential area, Chicago, IL (APWA, 1968).

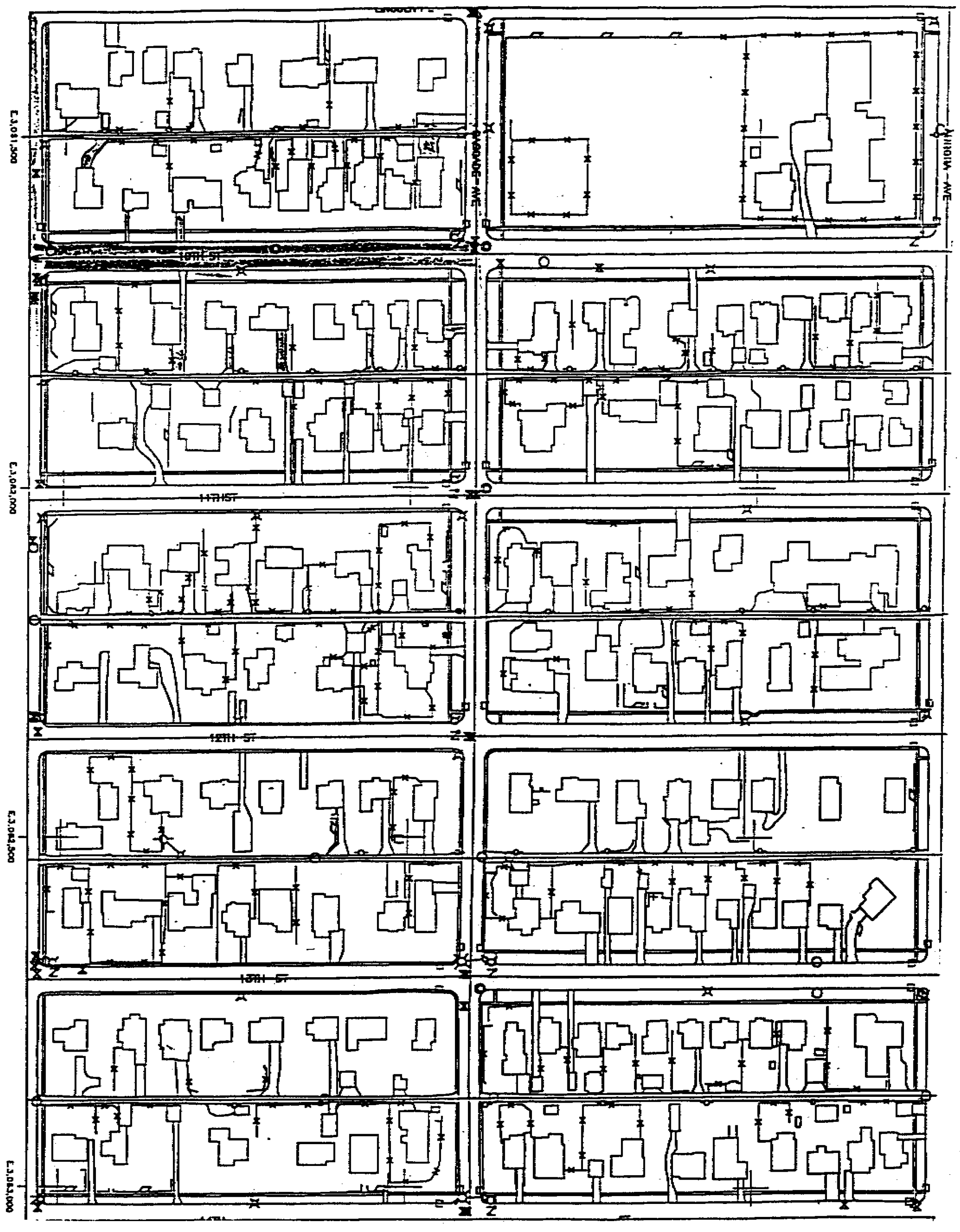

Figure 2-10. Aerial view of 10 blocks in an older neighborhood in Boulder, CO.

Table 2-7. Attributes of dwelling units located on traditional grid street network-total imperviousness**.**

Description	Dwelling Units/ Block	Living Area sq. ft./DU	Dwelling Units/Lot	Footprint Living Area sq. ft./DU	Garage Roof sq. ft./DU	Driveway sq. ft./DU	Street sq. ft./DU	Walkways sq. ft./DU	Alley sq. ft./DU	Transport sq. ft./DU	Total Impervious Area sq. ft./DU	Total Pervious Area sq. ft./DU	Total Area sq. ft./DU	% Total Impervious Area	Imp. Area Transport/ Living	Areas for Vehicles: Parking sq. ft./DU	Areas for Vehicles: Traffic sq. ft./DU	Areas for Vehicles: Total sq. ft./DU
1. Original inner city houses	48	800	1	800	160	50	701	716	209	1,836	2,636	1,902	4,538	58.1%	2.29	526	386	911
2. Larger bungalows	36	1,170	1	1,170	320	50	935	781	278	2,364	3,534	2,516	6,050	58.4%	2.02	791	514	1,306
3. Two flats-two story	72	1,170	2	585	160	25	468	391	139	1,182	1,767	1,258	3,025	58.4%	2.02	395	257	653
Mean	52	1,047	1.33	852	213	42	701	629	209	1,794	2,646	1,892	4,538	58.3%	2.11	571	386	956
4. Houses w. side driveway/rear garage	24	1,500	1	1,500	320	800	1,403	912	0	3,434	4,934	4,141	9,075	54.4%	2.29	1,751	771	2,523
5. Houses with driveway/garage in front.	20	2,100	1	2,100	320	600	1,683	990	0	3,593	5,693	5,197	10,890	52.3%	1.71	1,677	926	2,603
6. Low density house	12	2,400	1	2,400	320	600	2,806	1,303	0	5,028	7,428	10,722	18,150	40.9%	2.10	2,182	1,543	3,725
Mean	19	2,000	1	2,000	320	667	1,964	1,068	0	4,019	6,019	6,687	12,705	49.2%	2.03	1,870	1,080	2,950

Table 2-8. Attributes of dwelling units located on traditional grid street network-directly connected imperviousness**.**

Description	Dwelling Units/ Block	Living Area sq. ft./DU	Dwelling Units/Lot	Footprint Living Area sq. ft./DU	Garage Roof sq. ft./DU	Driveway sq. ft./DU	Street sq. ft./DU	Walkways sq. ft./DU	Alley sq. ft./DU	Transport sq. ft./DU	DC Impervious Area sq. ft./DU	Pervious Area sq. ft./DU	Total Area sq. ft./DU	% DC Impervious Area	DCIA Transport/ Living	Areas for Vehicles: Parking sq. ft./DU	Areas for Vehicles: Traffic sq. ft./DU	Areas for Vehicles: Total sq. ft./DU
1. Original inner city houses	48	800	1	800	40	25	701	179	209	945	1,745	2,792	4,538	38.5%	1.18	381	386	766
2. Larger bungalows	36	1,170	1	1,170	80	25	935	195	278	1,235	2,405	3,645	6,050	39.8%	1.06	526	514	1,040
3. Two flats-two story	72	1,170	2	585	80	13	468	98	139	658	1,243	1,782	3,025	41.1%	1.12	303	257	560
Mean	52	1,047	1.33	852	67	21	701	157	209	946	1,798	2,740	4,538	39.8%	1.12	403	386	789
4. Houses w. side driveway/rear garage	24	750	1	750	80	200	1,403	228	0	1,910	2,660	6,415	9,075	29.3%	2.55	911	771	1,683
5. Houses with driveway/garage in front.	20	693	1	693	80	150	1,683	248	0	2,161	2,854	8,037	10,890	26.2%	3.12	987	926	1,913
6. Low density house	12	600	1	600	80	150	2,806	326	0	3,361	3,961	14,189	18,150	21.8%	5.60	1,492	1,543	3,036
Mean	38	690	1.19	779	72	83	1,242	204	119	1,602	2,381	5,657	8,038	33.8%	2.25	715	683	1,398

Notes;
DU-dwelling unit
Street area includes side streets at the end of the block.

Average Total Imperviousness/DU

Item	%	Sq. ft.
Living area	33.2%	2,000
Garage	5.3%	320
Driveway	11.1%	667
Alley	0.0%	0
Street	32.6%	1,964
Walkways	17.8%	1,068
Total	100.0%	6,019

Average Directly Connected Imperviousness/DU

Item	%	Sq. ft.
Living area	34.1%	890
Garage	2.8%	72
Driveway	3.2%	83
Alley	4.6%	119
Street	47.6%	1,242
Walkways	7.8%	204
Total	100.0%	2,611

Imperviousness in Pre-Automobile Era

Categories 1 to 3 in Tables 2-7 and 2-8 represent the pre-automobile era and are all served by alleys. Densities range from 5.2 to 14.4 dwelling units per acre. Garages are assumed to exist although they probably were used for other purposes and were called sheds. The total imperviousness for these three land uses is about 58% and the DCIA is about 40%. The rooftops are directly connected to the sewer because of the higher densities and lack of sufficient pervious areas to receive the roof runoff. The transition point at which roof runoff can be discharged onto pervious areas needs to be determined based on local conditions. Even for this pre-automobile condition, transportation related imperviousness is over twice the imperviousness caused by the living area. However, walkways (front, rear, and side) are a significant part of the transportation component.

Pre-Expressway Neighborhoods

Large-scale development began after World War II with communities such as Levittown, NY (Southworth and Ben-Joseph 1997). This residential street is typical of the design standards for suburban developments, (i.e., wide streets with curb and gutter, sidewalks on both sides of the street, paved driveways, and garages or carports). Most newer suburban communities followed federal street standards promulgated by FHA during the 1930's.

Results for Pre-Expressway Era

Cases 4 to 6 in Tables 2-8 and 2-9 represent developments that accommodate the automobile. The first phase of this transition was to eliminate alleys and construct side drives to garages in the rear of the house. Then, garages were attached directly to the house, and lastly the houses grew in size. The number of dwelling units per gross acre ranges from 2.4 to 4.8. The declining dwelling unit densities reduced total imperviousness to 41 to 54%, less than traditional developments, but not proportionately less. The DCIA ranges from 22 to 29%, a significant decrease from 38 to 41% associated with earlier developments. The major reduction in DCIA is due to disconnecting roof downspouts and eliminating alleys. However, the DCIA area per dwelling unit increases substantially from an average of about 1,800 to 3,200 square feet due to the larger garages, driveways, and lot sizes.

Post-Expressway Neighborhoods

The availability of expressways allowed people to move even farther from the core urban areas. The major impact of the expressways is the need for more vehicles per family and with cheaper land and increased economic prosperity associated with a healthy economy and the trend towards two working parents, house and lot sizes continued to grow. Thus, contemporary houses have larger garages and driveways, and more street frontage per house. A sample of 24 contemporary homes taken from Sunset (1992) was used to evaluate the expected nature of imperviousness in contemporary housing. The sample consisted of 13 single story houses and 11 two story houses.

One Story Houses: The results for the single story houses are shown in Tables 2-9 and 2-10 for total imperviousness and DCIA, respectively. No explicit street pattern is assumed for this development. Thus, the street and sidewalk areas are underestimated, probably by 10-15%. Development densities range from 2.0 to 5.4 houses per acre. The results indicate that total imperviousness is relatively insensitive to housing density and ranges from 36 to 48%. Total imperviousness actually increases as dwelling unit density decreases due to larger garages, longer driveways and more street length per house. On the average, the living area constitutes 41% of the total imperviousness, but only 22% of the DCIA. Thus, the transportation component dominates as the primary source of total, and more importantly, directly connected imperious area.

Measured in absolute terms in terms of total impervious area per house, the results indicate that total impervious area per house increases from about 4,000 square feet to almost 8,700 square feet as the living area goes from 1,272 square feet to 4,284 square feet. Parking is responsible for most of the total impervious area for vehicles, an average of 2,041 square feet of parking compared to an average of 811 square feet for traffic movement. Only about half of the impervious area for parking is directly connected. Thus, its impact is lessened. Overall, streets constitute over 61% of the DCIA. The street is used both for parking and traffic flow.

Two-story Houses: The results for the two story houses are shown in Tables 2-11 and 2-12 for total imperviousness and DCIA, respectively. No explicit street pattern is assumed for this development. Thus, the street and sidewalk areas are underestimated, probably by 10-15%. Development densities range from about 2.9 to 6.9 houses per acre. The results indicate that total imperviousness is relatively insensitive to housing density and ranges from 31 to 80%. Total imperviousness actually increases as dwelling unit density decreases due to larger garages, longer driveways and more street length per house. On the average, the living area constitutes 37% of the total imperviousness, but only 20% of the DCIA. As before, the transportation component dominates as the primary source of total and more importantly, directly connected imperious area.

Measured in absolute terms in terms of total impervious area per house, the results indicate that total impervious area per house increases from about 2,800 square feet to almost 6,376 square feet as the living area goes from 1,193 square feet to 3,728 square

Table 2-9. Attributes of dwelling units located on traditional grid street network-total imperviousness.

Description	Dwelling Units/ Block	Living Area sq. ft./DU	Dwelling Units/Lot	Footprint Living Area sq. ft./DU	Garage Roof sq. ft./DU	Driveway sq. ft./DU	Street sq. ft./DU	Walkways sq. ft./DU	Alley sq. ft./DU	Transport sq. ft./DU	Total Impervious Area sq. ft./DU	Total Pervious Area sq. ft./DU	Total Area sq. ft./DU	% Total Impervious Area	Imp. Area Transport/ Living	Areas for Vehicles: Parking sq. ft./DU	Areas for Vehicles: Traffic sq. ft./DU	Areas for Vehicles: Total sq. ft./DU
1. Original inner city houses	48	800	1	800	160	50	701	716	209	1,836	2,636	1,902	4,538	58.1%	2.29	526	386	911
2. Larger bungalows	36	1,170	1	1,170	320	50	935	781	278	2,364	3,534	2,516	6,050	58.4%	2.02	791	514	1,305
3. Two flats-two story	72	1,170	2	585	160	25	468	391	139	1,182	1,767	1,258	3,025	58.4%	2.02	395	257	653
Mean	52	1,047	1.33	852	213	42	701	629	209	1,794	2,646	1,892	4,538	58.3%	2.11	571	386	956
4. Houses w. side driveway/rear garage	24	1,500	1	1,500	320	800	1,403	912	0	3,434	4,934	4,141	9,075	54.4%	2.29	1,751	771	2,523
5. Houses with driveway/garage in front.	20	2,100	1	2,100	320	600	1,683	990	0	3,593	5,693	5,197	10,890	52.3%	1.71	1,677	926	2,603
6. Low density house	12	2,400	1	2,400	320	600	2,805	1,303	0	5,028	7,428	10,722	18,150	40.9%	2.10	2,182	1,543	3,725
Mean	19	2,000	1	2,000	320	667	1,964	1,068	0	4,019	6,019	6,687	12,705	49.2%	2.03	1,870	1,080	2,950

Table 2-10. Attributes of dwelling units located on traditional grid street network-directly connected imperviousness.

Description	Dwelling Units/ Block	Living Area sq. ft./DU	Dwelling Units/Lot	Footprint Living Area sq. ft./DU	Garage Roof sq. ft./DU	Driveway sq. ft./DU	Street sq. ft./DU	Walkways sq. ft./DU	Alley sq. ft./DU	Transport sq. ft./DU	DC Impervious Area sq. ft./DU	Pervious Area sq. ft./DU	Total Area sq. ft./DU	% DC Impervious Area	DCIA Transport/ Living	Areas for Vehicles: Parking sq. ft./DU	Areas for Vehicles: Traffic sq. ft./DU	Areas for Vehicles: Total sq. ft./DU
1. Original inner city houses	48	800	1	800	40	25	701	179	209	945	1,745	2,792	4,538	38.5%	1.18	381	386	766
2. Larger bungalows	36	1,170	1	1,170	80	25	935	195	278	1,235	2,405	3,645	6,050	39.8%	1.06	526	514	1,040
3. Two flats-two story	72	1,170	2	585	80	13	468	98	139	658	1,243	1,782	3,025	41.1%	1.12	303	257	560
Mean	52	1,047	1.33	852	67	21	701	157	209	946	1,798	2,740	4,538	39.8%	1.12	403	386	789
4. Houses w. side driveway/rear garage	24	750	1	750	80	200	1,403	228	0	1,910	2,660	6,415	9,075	29.3%	2.55	911	771	1,683
5. Houses with driveway/garage in front.	20	693	1	693	80	150	1,683	248	0	2,161	2,854	8,037	10,890	26.2%	3.12	987	926	1,913
6. Low density house	12	600	1	600	80	150	2,805	326	0	3,361	3,961	14,189	18,150	21.8%	5.60	1,492	1,543	3,035
Mean	38	690	1.19	779	72	83	1,242	204	119	1,602	2,381	5,657	8,038	33.8%	2.25	715	683	1,398

Notes;
DU-dwelling unit
Street area includes side streets at the end of the block.

Average Total Imperviousness/DU

Item	%	Sq. ft.
Living area	33.2%	2,000
Garage	5.3%	320
Driveway	11.1%	667
Alley	0.0%	0
Street	32.6%	1,964
Walkways	17.8%	1,068
Total	100.0%	6,019

Average Directly Connected Imperviousness/DU

Item	%	Sq. ft.
Living area	34.1%	890
Garage	2.8%	72
Driveway	3.2%	83
Alley	4.6%	119
Street	47.6%	1,242
Walkways	7.8%	204
Total	100.0%	2,611

Table 2-11. Attributes of thirteen contemporary one story houses-total imperviousness.

	% DCIA	25.00%	25.00%	25.00%	100.00%	25.00%							Area for vehicles		
Number	Living Area sq. ft.	Living+ porch/storage sq. ft.	Garage Roof sq. ft.	Driveway sq. ft.	Street sq. ft.	Walkways sq. ft.	Transport sq. ft.	Impervious Total sq. ft.	Pervious Total sq. ft.	Grand Total sq. ft.	% Total Impervious Area	Imp. Area Transport/ Living	Parking sq. ft.	Traffic sq. ft.	Total sq. ft.
1	1,272	1,272	462	640	1,309	285	2,696	3,968	5,888	9,856	40.3%	2.12	1,718	693	2,411
2	1,283	1,300	400	600	1,224	260	2,484	3,784	4,784	8,568	44.2%	1.91	1,576	648	2,224
3	1,300	1,560	441	880	1,173	245	2,739	4,299	4,671	8,970	47.9%	1.76	1,873	621	2,494
4	1,418	1,668	484	800	1,411	315	3,010	4,678	5,033	9,711	48.2%	1.80	1,948	747	2,695
5	1,428	1,478	400	400	1,139	235	2,174	3,652	4,388	8,040	45.4%	1.47	1,336	603	1,939
6	1,458	1,458	400	880	1,309	285	2,874	4,332	5,601	9,933	43.6%	1.97	1,896	693	2,589
7	1,689	1,689	576	500	1,190	250	2,516	4,205	4,685	8,890	47.3%	1.49	1,636	630	2,266
8	2,000	2,000	672	900	1,428	320	3,320	5,320	8,036	13,356	39.8%	1.66	2,244	756	3,000
9	2,180	2,280	529	600	1,496	340	2,965	5,245	8,659	13,904	37.7%	1.30	1,833	792	2,625
10	2,400	2,660	550	1,000	2,006	490	4,046	6,706	11,938	18,644	36.0%	1.52	2,494	1,062	3,556
11	2,968	3,208	450	1,200	2,040	500	4,190	7,398	13,002	20,400	36.3%	1.31	2,610	1,080	3,690
12	3,735	3,935	768	800	2,210	550	4,328	8,263	12,537	20,800	39.7%	1.10	2,608	1,170	3,778
13	4,284	4,384	630	1,200	1,989	485	4,304	8,688	13,542	22,230	39.1%	0.98	2,766	1,053	3,819
Mean	2,109	2,222	520	800	1,533	351	3,204	5,426	7,905	13,331	42.0%	2	2,041	811	2,853

Table 2-12. Attributes of thirteen contemporary one story houses-directly connected imperviousness.

													Area for vehicles		
Number	Living Area sq. ft.	Living+ porch/storage sq. ft.	Garage Roof sq. ft.	Driveway sq. ft.	Street sq. ft.	Walkway sq. ft.	Transport sq. ft.	DC Imperv. Total sq. ft.	Perv. Total sq. ft.	Grand Total sq. ft.	% DCIA	Imp. Area Transport/ Living	Parking sq. ft.	Traffic sq. ft.	Total sq. ft.
1	1,272	318	116	160	1,309	71	1,656	2,928	6,928	9,856	29.7%	5.2	892	693	1,585
2	1,283	325	100	150	1,224	65	1,539	2,822	5,746	8,568	32.9%	4.7	826	648	1,474
3	1,300	390	110	220	1,173	61	1,565	2,865	6,106	8,970	31.9%	4.0	882	621	1,503
4	1,418	417	121	200	1,411	79	1,811	3,229	6,482	9,711	33.2%	4.3	985	747	1,732
5	1,428	370	100	100	1,139	59	1,398	2,826	5,214	8,040	35.1%	3.8	736	603	1,339
6	1,458	365	100	220	1,309	71	1,700	3,158	6,775	9,933	31.8%	4.7	936	693	1,629
7	1,689	422	144	125	1,190	63	1,522	3,211	5,680	8,890	36.1%	3.6	829	630	1,459
8	2,000	500	168	225	1,428	80	1,901	3,901	9,455	13,356	29.2%	3.8	1,065	756	1,821
9	2,180	570	132	150	1,496	85	1,863	4,043	9,861	13,904	29.1%	3.3	986	792	1,778
10	2,400	665	138	250	2,006	123	2,516	4,916	13,728	18,644	26.4%	3.8	1,332	1,062	2,394
11	2,968	802	113	300	2,040	125	2,578	5,546	14,855	20,400	27.2%	3.2	1,373	1,080	2,453
12	3,735	984	192	200	2,210	138	2,740	6,475	14,326	20,800	31.1%	2.8	1,432	1,170	2,602
13	4,284	1,096	158	300	1,989	121	2,568	6,852	15,378	22,230	30.8%	2.3	1,394	1,053	2,447
Mean	2109	556	130	200	1,533	88	1,950	4,059	9,272	13,331	31.1%	3.8	1,051	811	1,863

Total Imperviousness		
Living area	40.96%	2222
Garage	9.59%	520
Driveway	14.74%	800
Street	28.25%	1533
Sidewalk	6.46%	351
Total	0.00%	5426

DC Imperviousness		
Living area	22.17%	556
Garage	5.19%	130
Driveway	7.98%	200
Street	61.16%	1533
Sidewalk	3.50%	88
Total	100.00%	2506

feet. Most of the total impervious area for vehicles is for parking, an average of 1,725 square feet of parking compared to an average of 662 square feet for traffic movement. Only about half of the impervious area for parking is directly connected. Thus, its impact is lessened. Overall, streets constitute over 63% of the DCIA. The street is used both for parking and traffic flow.

General Conclusions Regarding the Effect of Changing Land Use

Three 20th century land use patterns: pre-automobile, pre-expressway, and post-expressway, were evaluated. The major trend over the century has been towards decreased development densities. Densities greater than about eight dwelling units per acre are difficult to achieve with automobiles since insufficient parking by contemporary standards is available. Therefore, the earlier impact of the automobile was to retrofit existing neighborhoods and foster growth in nearby suburbs that could accommodate automobiles as a major user of land. The development of expressways allowed people to move even farther out of the core urban areas. This movement resulted in even more dependence on automobiles and led to even lower development densities. Thus, the overall results of the above analysis can be captured by showing the effect of density on infrastructure utilization. The results are summarized below.

Higher densities significantly reduce the lengths of streets, water mains, sanitary and storm sewers needed per dwelling unit as shown in Table 2-13 and Figure 2-11 for the five acre block studied as part of traditional developments. The general equation for feet of street per dwelling unit for this five acre case is:

$$L = \frac{198}{DUD} \qquad \text{Equation 2-1}$$

where *L* = feet of street per dwelling unit, and
DUD = dwelling units per gross acre.

The length shown in Equation 2-1 consists of one half of the street frontage per dwelling unit plus a prorated share of the side street length. Urban sprawl is considered to be lot densities of three per acre or less. As indicated by Figure 2-11 , the street length per dwelling unit increases rapidly at lower densities reaching 100 feet per dwelling unit at two units per acre, four times the length at eight units per acre. This length per dwelling unit is a critical parameter because the street, water main, sanitary sewer, and storm sewer lengths all increase in the same proportion.

The service area per household increases according to the same type of relationship as for infrastructure length, that is:

$$A = \frac{43560}{DUD} \qquad \text{Equation 2-2}$$

where *A* = square feet of area per dwelling unit, and
DUD = dwelling units per gross acre.

Table 2-13: Relationship between street length and dwelling unit density for a five acre rectangular block of dimensions 660 feet by 330 feet.

DUD Dwelling Unit Density (dwelling units/acre)	Street Length Per Dwelling Unit (feet)
2	99.0
3	66.0
4	49.5
5	39.6
6	33.0
7	28.3
8	24.8
9	22.0
10	19.8
11	18.0
12	16.5
13	15.2
14	14.1
15	13.2

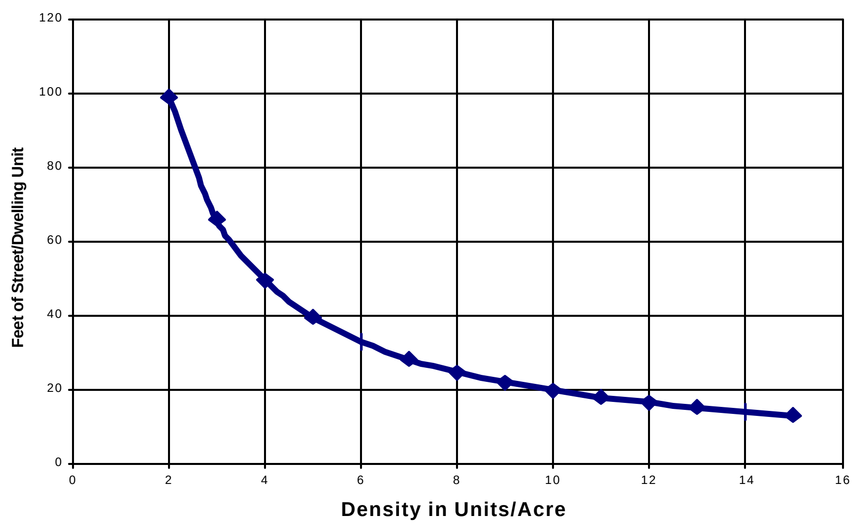

Figure 2-11. Relationship between street length and dwelling unit density for a five acre rectangular block of dimensions 660 feet by 330 feet.

The results are shown in Table 2-14 and Figure 2-12. Lot area per dwelling unit is also a critical parameter in determining infrastructure costs. Larger lots generate an increased demand for lawn watering, the largest source of variability in urban water supply.

Another significance of lot area is that storm sewer peak design flows for small catchments are typically calculated using the Rational formula,

$$Q = CiA \qquad \text{Equation 2-3}$$

where Q = peak discharge rate,
C = runoff coefficient that depends on the land use,
i = rainfall intensity, and
A = drainage area.

Q increases linearly with drainage area in Equation 2-3. The only offsetting factor is if the runoff coefficient decreases as A increases. The runoff coefficient is often assumed to equal the imperviousness as shown in Figure 2-13. Using a database of DUD as a function of total and DCIA developed as part of this study, a relationship between imperviousness and DUD was derived. The results, shown in Figure 2-14, indicate that total imperviousness decreases from about 60% at a DUD of 10 to about 40% at a DUD of two. The net effect, shown in Table 2-15 is more than a three-fold increase in *CA* and, therefore, peak discharge rate, as densities decrease from 10 to two DU/gross acre.

Table 2-14. Effect of dwelling unit density on CA in the Rational formula

DUD Dwelling Unit Density (dwelling units/acre)	A Lot Area Per Dwelling (sq. ft.)	I Imperviousness (%)	CA In (sq. ft.)
2	21,780	40	8,712
10	4,356	60	2,616

The preceding results imply that serving contemporary lower density residential developments is significantly more expensive per dwelling unit than it is for higher density developments. Is this cost reflected in the charges for services rendered? If the new users paid system development charges (SDC) that covered the cost of the local improvements, then a significant part of this added cost is equitably assigned. Most of the charges for water supply are assessed based on water use. Per capita indoor water use is fairly constant. However, outdoor water use depends on the demand for irrigation water which ranges from insignificant in the northeastern U.S. to dominant in the arid southwestern U.S. If irrigation is not a significant water use and SDC's were not assessed, then the lower density developments are being subsidized since they require more piping per unit of water delivered. If irrigation is significant, then the equity of the charges depends on the charge for outdoor water use. Wastewater charges are either fixed per household or assessed based on indoor water use. This charging procedure is unfair to people living in higher density areas since they use less piping per family. Stormwater charges are a fixed amount per month, or are based on impervious area. Only in the latter case are charges assessed in proportion to the contribution to the problem.

Table 2-15: Relationship between dwelling unit density and area per lot.

DUD (Dwelling Unit Density) **(dwelling units/acre)**	**Lot Area** **(sq. ft.)**
2	21,780
3	14,520
4	10,890
5	8,712
6	7,260
7	6,223
8	5,445
9	4,840
10	4,356
11	3,960
12	3,630
13	3,351
14	3,111
15	2,904

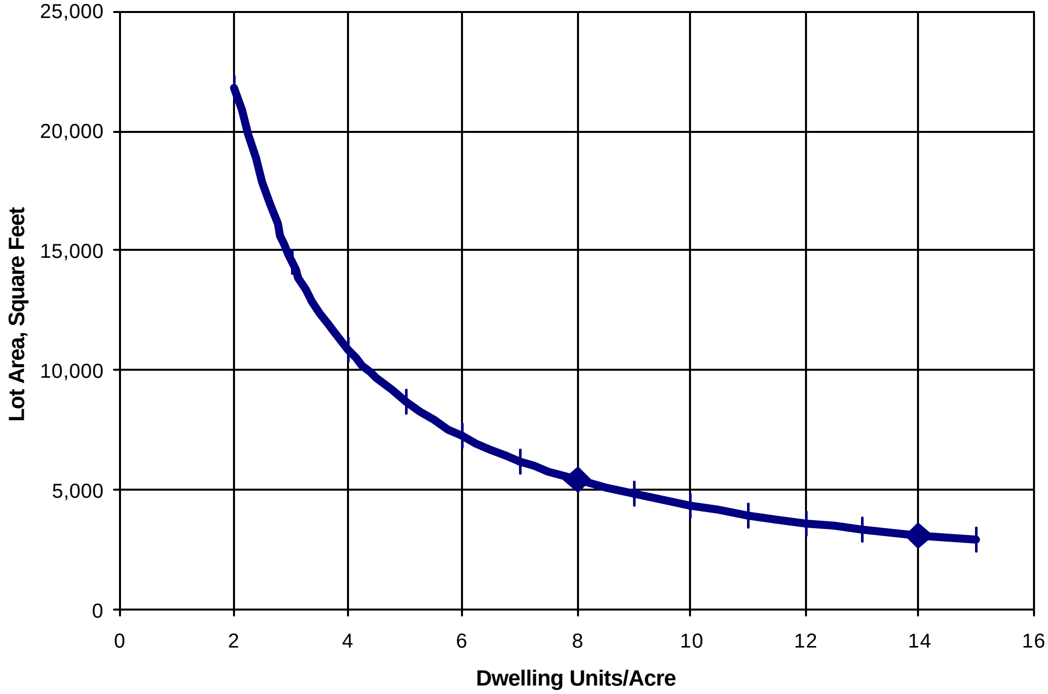

Figure 2-12. Relationship between dwelling unit density and area per lot.

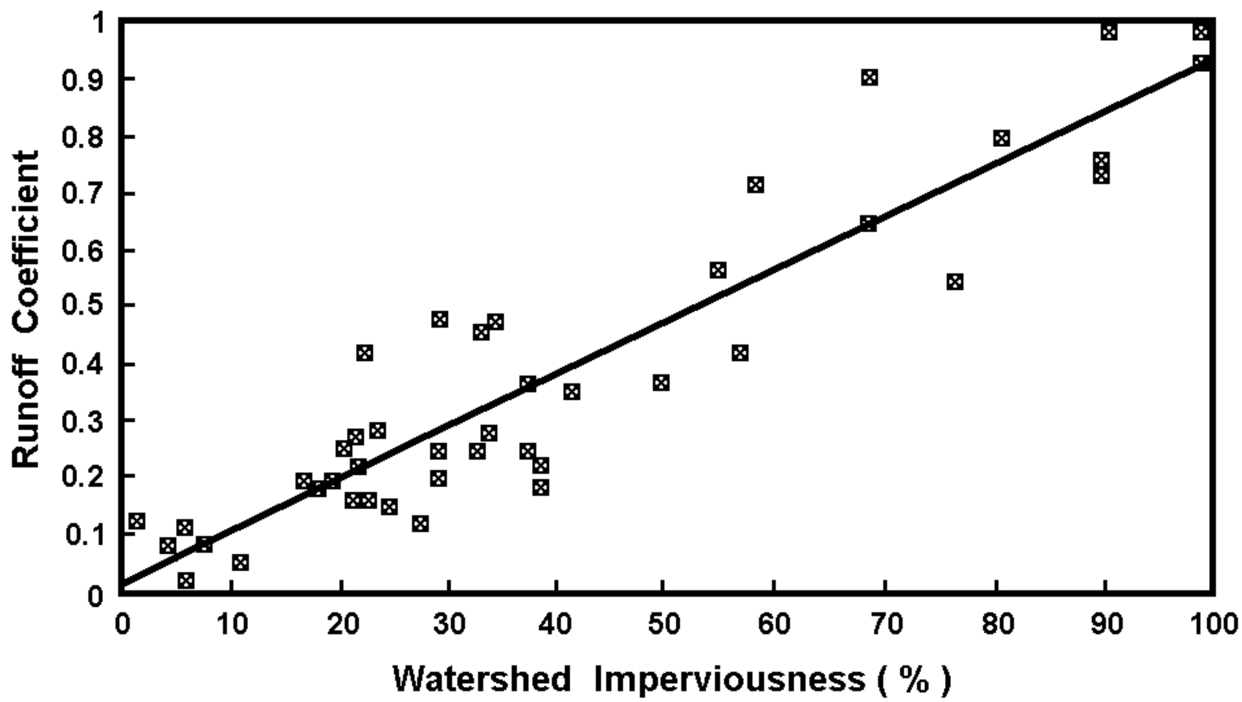

Figure 2-13. Watershed imperviousness and the storm runoff coefficient (WEF/ASCE 1998).

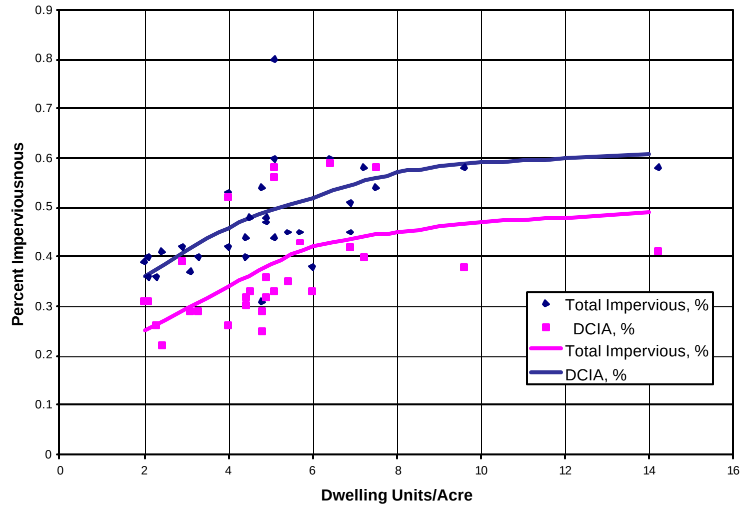

Figure 2-14. Effect of dwelling unit density on imperviousness.

In summary, overall dwelling unit density is a good measure of the impact of residential development on infrastructure. Densities above about eight dwelling units per acre are difficult to achieve in areas that are dependent on the automobile for transportation since there is insufficient space to accommodate the automobile with existing land use zoning requirements.

The quantity of stormwater runoff per person has grown dramatically during the past century. The following factors are the major causes of this growth:

1. The introduction of automobiles into cities: Automobiles are very inefficient people movers in cities with regard to the space and generation of pollutants. A vehicle weighing 2,500 to 4,000 pounds is used to carry a 150 pound person around the city. This vehicle is only used about 1-5% of the time. When not in use, it must be parked. Each off-street parking space uses 300-400 square feet of impervious area. In residential areas, transportation related imperviousness accounts for over 65% of total imperviousness and nearly 80% of the DCIA. Within residential neighborhoods alone, about 1.25 to 2.0 square feet of impervious area is generated for transportation for every square foot of living area. Similar ratios exist for commercial areas.

2. The trend towards larger houses: House sizes have grown significantly in the past 40 years from about 1,000 square feet to over 2,000 square feet as families move to outlying areas.

3. The trend towards larger lots: Lot sizes have also grown significantly as families provide recreation and open space on each lot as opposed to using common

areas. Lot sizes have also had to grow to accommodate larger garages and driveways.

4. The trend towards smaller families: Smaller family sizes and larger houses cause the need for support infrastructure per capita to increase accordingly.

5. The green trend of providing more open space as part of the development: This open space further reduces densities and increases sprawl. Properly designed, some or all of this open space could provide essential water infrastructure functions such as stormwater retention.

Given that demands for stormwater management have increased dramatically due to the pervasive influence of the automobile, the trend towards lower density sprawl development, and the desire for open space, can any of these patterns be changed? The individual sources of imperviousness and their nature are discussed in the following sections.

Components of Urban Land Use and Stormwater Problems

The components of urban land use are examined in this section. For each component, the relative importance as a source of stormwater quantity and quality problems is discussed. The controllability of stormwater from each component is then analyzed.

Streets and Highways

Urban street patterns have changed during the 20th century, with the automobile having a major influence on street design at all levels. Southworth and Ben-Joseph (1995) summarize this evolution. They trace the major change in philosophy for street design to the 1930s when the federal government became involved in developing guidelines for subdivisions as part of its program to insure home mortgages. The traditional pattern is the gridiron with typical block dimensions of 1/8 by 1/16 of a mile as was shown earlier. The most radical departure from this pattern was the Radburn development in New Jersey that used narrower streets in the neighborhood.

In 1936, the Federal Housing Administration (FHA) rejected the grid pattern for residential neighborhoods, and has continued this policy of preferring other street layouts (Southworth and Ben-Joseph 1995). Their primary reasons for rejecting the gridiron pattern are:

1. It requires more paved area than necessary because all residential streets are built to the same specifications.

2. It requires more expensive type of pavement since the traffic is dispersed throughout the neighborhood and thus the streets must be designed to a higher standard.

3. This heavier traffic demand creates a hazard.

4. The gridiron layout is monotonous and uninteresting.

The FHA recommended a hierarchical street pattern. For residential streets, they recommended curvilinear alignments, cul-de-sacs, and courts. Desirable design criteria promulgated by the FHA included (Southworth and Ben-Joseph 1995):

1. Layout should discourage through traffic.

2. Minimum width of a residential street should be 50 feet with 24 feet of pavement, eight foot planting/utility strips and four foot walks.

3. Cul-de-sacs are the most attractive street layout for family dwellings.

4. Minimum setbacks for streets should be 15 feet.

5. Front yard should avoid excessive planting, for a more pleasing and unified effect along the street.

These early FHA guidelines had a tremendous influence on residential development in the United States because of their financial leverage over developers and home buyers. The Institute of Transportation Engineers (ITE) has also had a major influence on residential street design. Their perspective is heavily influenced by traffic flow and parking considerations. They recommend (Southworth and Ben-Joseph 1995):

1. Right of way minimum of 60 feet.

2. Pavement width of 32-34 feet.

3. Cul-de-sacs should have a maximum length of 1,000 feet with a 50-foot radius at the end.

4. Parking lanes should be 8 feet in width.

The influence of these street design standards on drainage and stormwater quality does not seem to have been a significant factor in the decision making process.

The American Association of State Highway and Transportation Officials (AASHTO) has been responsible for developing the design standards for highways and streets. The primary reference is A Policy on Geometric Design of Highways and Streets (AASHTO 1984).

According to Khisty (1990), 10-13 foot lane widths predominate in the United States with 12 feet being the most common. The use of 11 foot lane widths is acceptable in urban areas due to higher right-of-way costs. Ten-foot lane widths are only acceptable on low speed urban streets.

Ewing (1996) divides residential streets into the categories of arterial, collector/sub-collector, and access. Four types of residential streets (i.e., non-arterials) exist. They are:

1. Collector
2. Sub-collector
3. Access-looped
4. Access-dead end

Southworth and Ben-Joseph (1997) provide a history of urban streets, a critique on current practices, and project the expected nature of streets in urban areas. They estimate that, worldwide, more than one third of all developed urban land is devoted to roads, parking lots, and other automobile infrastructure. In the urban U.S., about one half of the land is used for this purpose. In automobile oriented cities like Los Angeles, the percentage increases to two thirds (Hanson 1992, Renner 1988). These estimates are compatible with the results presented in the previous section.

Traditional gridiron street patterns were rejected as bad practice beginning in the 1930's based on recommendations from the federal government. They are enjoying a comeback as part of the interest in the new urbanism. Chellman (1997) provides a current summary of the pros and cons of traditional streets for neighborhoods. Features of traditional streets include a high degree of connectivity that maximizes mobility for non-motorists.

Transportation engineers tend to design streets to maximize convenience for the automobile subject to safety constraints. Recently, designers have attempted to recast the purpose of streets as multi-purpose components of the community with much more of a pedestrian orientation. Shared streets provide a multi-purpose use of residential streets. These streets have gained favor internationally but have not yet gained widespread acceptance in the U.S. Key impediments in the U.S. include dependency on automobiles, and concerns of liability if existing street standards are changed. Portland, OR is one of the few cities in the U.S. that is rethinking its approach to residential streets with its skinny streets program (Southworth and Ben-Joseph 1997). They have reduced street widths to 20-26 feet and have installed many traffic calming devices.

Streets have the potential to play a major role in stormwater management. Walesh (1989, Chapter 5) presents an analysis of the ability of a typical urban street, with curb and gutter, to temporarily convey or store stormwater runoff from major runoff events. Skokie, IL implemented an innovative approach to its streets by using them to intentionally convey and store stormwater in a controlled fashion so that combined sewers do not surcharge and back up into basements (Walesh and Carr, 1998).

Stormwater control is achieved in this cost-effective system using on-street berms coupled with catch basin flow regulators and, where needed, subsurface tanks.

Street Classification and Utilization

The Federal Highway Administration (FHWA) tabulates a variety of street related statistics that can be obtained on the internet at *http:/www.bts.gov/cgi-bin/stat/final_out.pl.* Results for urban areas in the United States are shown in Table 2-16. The major traffic carrying components of the highway system constitute only about 9% of the road mileage in urban areas. Local streets that carry little traffic constitute the bulk of the mileage, nearly 70%. Parking is allowed on the lesser used streets; thus, most of the parking is associated with local and collector streets. While the interstates, freeways, other expressways, and principal arterial streets constitute only 9.1% of the miles, they carry 58% of the traffic. At the other extreme, local streets, constituting 69.5% of the street length, carry only 13.8% of the traffic. Thus, in terms of managing imperviousness, the lesser used local streets are the prime candidates for evaluating whether they could be reduced in size.

The results of Table 2-16 also suggest that the primary sources of traffic related stormwater pollution are the intensively used street systems. This may suggest a control strategy of providing more treatment for these intensively used streets. This much smaller impervious area may be more amenable to control than trying to deal with the entire impervious area of the city.

Table 2-16: Street mileage in the U.S.

Urban	Miles of road	% of urban
Interstate	13,307	1.6%
Other freeways/expressways	9,022	1.1%
Other principal arterial	53,044	6.4%
Minor arterial	89,013	10.8%
Collector	87,918	10.6%
Local	574,119	69.5%
Total Urban	826,423	100.0%

Recommendations for Residential Streets

Southworth and Ben-Joseph (1997) recommend the following principles for future residential streets:

1. Support varied uses of residential streets including children's play and adult recreation.

2. Design and manage street space for the comfort and safety of residents.
3. Provide a well-connected, interesting pedestrian network.
4. Provide convenient access for people who live on the street, but discourage through traffic; allow traffic movement, but do not facilitate it.
5. Differentiate streets by function.
6. Relate street design to the natural and historical setting.
7. Conserve land by minimizing the amount of land devoted to streets.

Contemporary texts on highway engineering do not deal with urban runoff problems. Khisty (1990) cautions of the need to evaluate air pollution and noise impacts as part of highway design. He doesn't mention highway runoff as a problem. Wright and Paquette (1996) describe conventional highway drainage design but do not discuss stormwater quality problems or the detrimental off-site impacts from highway runoff. The FHWA has sponsored several studies to address the issue of stormwater problems associated with highways. Young et al. (1996) present a detailed overview of highway runoff quality problems. For a more current view from FHWA on whether they consider highway runoff to be a serious problem, see http://www.tfhrc.gov/hnr20/runoff/runoff.html.

Streets and Stormwater Runoff

Whether residential streets are laid out in a grid-iron, curvilinear, or cul-de-sac format does not appear to have a major impact on the quantity of stormwater runoff per capita. The curvilinear and cul-de-sac layouts tend to have a larger impact per capita because of lower development densities. Schueler (1995) summarizes current national design standards for residential streets as shown in Table 2-17. Parking requires about eight feet of space and traffic lanes require about 10-12 feet per lane. Thus, streets with two way traffic and parking on both sides of the street would be 36 to 40 feet wide, if multi-purpose use is not incorporated in the design.

Average daily traffic (ADT) in vehicles per day is the common indicator of the utilization of streets for traffic. Schueler (1995) summarizes the expected traffic flow for various ADTs assuming 10 trips per dwelling unit per day and that the number of trips in the peak hour is 10% of the daily trips. The results are presented in Table 2-18 (Schueler 1995). As Schueler points out, for ADTs of 25 or less, it is reasonable to share parking and traffic lanes. Unfortunately, many cities have adopted regulations that require wide residential streets even in areas with little or no traffic.

Parking

The Institute of Transportation Engineers (ITE) recommends (Southworth and Ben Joseph, 1995) that on-street parking lanes should be eight feet in width and that driveway widths should be a minimum of 10 feet for one car, with a 20 foot-wide curb cut (five-foot flare on each end). According to Shoup (1995), off-street parking space per vehicle ranges from 300 to 350 square feet per space. This square footage includes the space itself, the access aisles, and the entry, exit area.

Table 2-17. Condensed summary of national design standards for residential streets (Schueler 1995).

Design Criteria	AASHTO	ITS	HEADWATER STREETS
Residential Street Categories	1	3, depending on use density	4, depending on ADT
Minimum Street Width	26 ft	22-27 ft>2 du 28-34 ft @2-6 du 36 ft< 6 du	16 ft (<100 ADT) 20 ft (100-500 ADT) 26 ft (500-3000 ADT) 32 ft (>6 du/ac)
Additional Right of Way	24 ft	24 ft	8 to 16 ft
Design Speed, Level Terrain	30 mph	30 mph	15 to 25 mph
Curb and Gutter	generally required	generally required	not required on collectors
Cul-de-sac Radii	30 ft	40 ft	30 ft
Turning Radii in Cul-de-sac	20 ft	25 ft	17 ft

Table 2-18. Relationship between number of dwelling units, traffic generation, and residential congestion (Schueler 1995).

No. of Single Family Homes	Average Daily Trips	Peak Trips Per Hour	Minutes between cars (average)	Minutes between cars (peak)
5	50	5	30	12
10	100	10	15	6
25	250	25	6	4
20	500	50	3	1.5
75	750	75	2	45 secs
100	1000	100	1.5	35 secs
150	1500	150	1	20 secs
300	3000	300	30 secs	10 secs

Shoup (1995) and Wilson (1995) summarize the origin of parking “requirements” in urban areas and the overall impact. According to Shoup (1995), motorists report free parking for 99 percent of all automobile trips. About 95% of automobile commuters say that they park free at work. A primary reason for such high use of cars to commute to work is that employers pay for parking. The average for seven case studies of the impact of parking fees on driving behavior is that 72 cars are driven to work per 100 employees if the employer pays for parking while only 53 cars are driven to work per 100 employees if the employee pays for parking (Shoup 1995). Recent state legislation in California requires employers to allow non-auto using employees to receive an equivalent cash payment to the amount of the subsidy for parking.

Between 1975 and 1993, the average number of parking spaces required by cities per 1,000 square feet of office space increased from 3.6 to 3.8 spaces (Shoup 1995). According to Wilson (1995), zoning codes typically require between three and five spaces per 1,000 gross square feet of office building area, with four spaces being the most popular requirement. At 350 square feet per parking space, this corresponds to 1.05 to 1.75 square feet of parking per square foot of office space. Similar ratios have been obtained for residential areas.

The actual estimate of saturation demand for parking is 2.4 spaces per 1,000 square feet of office space for driver paid parking to 3.1 spaces per 1,000 square feet for employer paid parking (Shoup 1995). According to Shoup (1995), over 91% of cities required more than this saturation demand. Wilson (1992) estimated an average requirement of 4.1 spaces per 1,000 square feet in southern California, with the average peak parking demand being only 56% of this capacity.

The primary justification for high parking requirements is to avoid spillover of parking from one parcel of land to others. However, if all facilities are designed for peak demand, often specified as the demand that only occurs 15 to 30 hours per year, then, by definition, large amounts of excess capacity will exist in the system since these peaks are not coincident. According to the Urban Land Institute (1982), specifying a design hour of the 20th busiest hour of the year, leaves spaces vacant more than 99% of the time and leaves half the spaces vacant at least 40% of the time.

Existing parking guidelines have evolved from observing practice around the United States. However, the database is observations on consumer behavior in lots where parking is provided free of charge. Thus, the existing standards are for the demand for parking if parking is free. According to Shoup (1995), virtually no research has been done to determine the optimal amount of parking since parking requirements are usually mandated by the local government agency. If a private developer was free to establish the amount of spaces to provide for his development, the developer would be expected to do a benefit-cost analysis and determine the number of spaces such that his net revenue was maximized.

Many residential streets carry relatively few vehicles each day. For example, streets serving less than 25 homes are so lightly traveled each day (and during peak hours) that shared parking and moving lanes make sense

The requirement for parking is typically estimated from the ITE parking manual (1987). Sample parking requirements are shown in Table 2-19, from Schueler (1995). According to Arnold and Gibbons (1996), the City of Olympia, WA found not only parking oversupply with vacancy rates of 60-70%, but also developers building an average of 51% more spaces than required by the City of Olympia.

Table 2-19. Parking demand ratios for selected land uses and activities (Schueler 1995).

Land Use	Parking Space Ratio Used	Range
Single Family Homes	2 spaces/du	1.5-2.5
Townhouses	2.25 spaces/du	1.5-2.5
Professional Office	1 space/200 sf gfa	150-330
Hotel/Motel	1 space/guest room	0.8-1.25
Retail	1 space/250 sf gfa	200-300
Convenience Store	1 space/300 sf gfa	100-500+es
Shopping Center	1 space/200 sf gfa	150-250
Movie Theatre	1 space/4 seats	3.3-5
Gas Station	2 spaces/pump (and 3 spaces)	
Industrial	1 space/1000 sf gfa	500-1200
Golf Course	4 spaces/hole	3-6.5
Nursing Home	1 space/3 beds	2-4+es
Day Care Center	1 space/8 children	4-10+es
Restaurant	1 space/50 sf gla	0-200
Marina	0.5 space/slip	0.26-0.7+es
Health Club	1 space/100 gfa+es	100-150
Church	1 space/5 seats	4-6
High School	many diverse ratios	
Medical/Dental Office	1 space/175 sf gfa	100-225

Notes: du=dwelling unit, sf=square feet, gla=gross leasable area, es= employee spaces, gfa=gross floor area.

A popular treatment option for parking lots is to deploy street sweepers. Street sweepers are also used for aesthetic purposes. Street sweepers pick up solids and debris. They are much less effective in removing other pollutants. Of course, street sweeping has no impact on the quantity of stormwater runoff. Another potentially effective method is to use porous or permeable pavement to reduce the runoff rates from parking areas.

An important question with regard to parking is the tradeoff between on-street and off-street parking. With contemporary subdivision design, the house has a two or three car garage, a driveway, and parking on the street in front of the house. In some cities, overnight parking on streets is prohibited, thereby increasing the need for off-street parking. A careful reexamination of these policies might show that current neighborhood parking requirements are overly conservative.

Lot Size

Lot sizes and associated dwelling unit densities were discussed previously with regard to estimating imperviousness. Lot size is seen to be a very good overall indicator of the amount of infrastructure needed to support residential development. Trends toward more automobiles and larger houses and a desire for "privacy" have resulted in much larger lot sizes. Demand for larger lot sizes might be reduced if the full costs of these larger lots were assessed on the property owners. In addition to promulgating regulations with regard to right-of-ways, cities often specify lot densities and minimum requirements (Schueler 1995). These minimum setback and related requirements further reduce allowable densities. As with right of ways, it is advisable to revisit these requirements for larger lot sizes.

Dwelling Unit Footprint

Urban dwelling units vary greatly in size as illustrated by these typical units and size ranges:

1. Single room:100-300 sq. ft.
2. Studio apartment: 300-500 sq. ft.
3. One-bedroom unit: 400-700 sq. ft.
4. Two-bedroom unit: 600-1,200 sq. ft.
5. Three-bedroom unit: 1,200-2,500 sq. ft.
6. Four-bedroom unit: 1,800-4,000 sq. ft.

Because of increasing affluence and more affordable housing, the median size of dwelling unit per family has steadily increased since World War II. For example, the median size of home increased from 912 square feet in 1948 to 1,113 square feet in 1963 (ULI 1968, p. 38).

The footprint of the dwelling unit (DU) is the amount of land it occupies. For single story DU's, the sizes of the DU and the footprint are very similar. The footprint is slightly larger due to roof overhang. The footprint is much less than the DU area if multiple level construction is used.

Stormwater runoff from buildings depends upon the roof area and whether the roof downspouts are directly connected to the storm sewer system. At densities of eight or more units per gross acre, the roof area should probably be connected directly to the stormwater control system because insufficient pervious area exists on the property itself. Treatment of roof runoff consists of controlling sources of atmospheric deposition, changing to more benign roofing materials, periodic cleaning of gutters, and disconnecting downspouts. The primary demand management approach is to encourage smaller roof areas by constructing multi-level buildings.

Covered Porches and Patios

The footprint of the DU is increased if covered porches are included in the house. Covered porches are an icon of traditional neighborhood development. One reason that porches fell out of favor is traffic noise. Porches add imperviousness to the property and appear to be regaining popularity. However, porches are a minor source of imperviousness and much of this imperviousness is not directly connected. Thus, no detailed evaluation of porches is included.

Patios may be constructed of permeable or impermeable material. They typically drain to adjacent pervious areas. Also, patios are not a major source of pollutant loadings. Thus, no separate analysis of patios is included.

Garages and Carports

Garages have emerged as an important land use in urban areas during the 20th century. Automobiles require about 200 square feet of garage space per car. As the number of automobiles has continued to increase, so has the number of garage spaces in DU's. Two and three car garages are now the norm for new house construction. The primary runoff from garage areas is from the rooftop. Thus, the impact depends upon whether the roof downspouts are directly connected to the sewer system or discharge to adjacent imperviousness such as driveways.

Treatment of roof runoff consists of controlling sources of atmospheric deposition, changing to more benign materials, and disconnecting downspouts. The primary demand management technique for garages and carports is to reduce the demand for the number of cars. In the United States, there are over 200 million cars for 250 million people. This corresponds to about one vehicle for every licensed driver in the United States. It is possible to have the number of cars per capita continue to increase as people have more than one car per capita.

Driveways

Driveways have become an important source of imperviousness in the 20th century as new developments had to accommodate a growing number of automobiles. The ITE (Southworth and Ben Joseph 1995) recommends minimum driveway widths of 10 feet for one car, with a 20 foot-wide curb cut (five-foot flare on each end). Driveways associated with garages are also an important land use. Four types of driveways need to be considered based on the location and orientation of the garage:

1. Attached, front facing garage
2. Attached, side facing garage
3. Attached, rear facing garage
4. Detached garage in rear of lot

Attached, Front Facing Garage: If the garage faces the street and is attached to the house, then the driveway width is usually the width of the number of garage spaces, or about 9-10 feet of width per car. The length of the driveway depends on the house setback. Minimum driveway lengths are dictated by having sufficient length so that a car can pull into the driveway and not block the sidewalk. Thus, a minimum driveway length is the sum of the distance from the street to the sidewalk (0-15 feet) plus the width of the sidewalk (four-six feet) if there is one plus the length of a car space or about 20 feet, or a total minimum driveway length of 20-41 feet. The extra house setback distance must be added to this minimum distance to get the total distance. For many houses, the paved area for the driveway exceeds the impervious area of the garage. Some, if not all, of the driveway drains to the street, thereby creating a significant source of directly connected impervious area.

Attached, Side or Rear Facing Garage: If the garage entrance faces the side of the house, then a narrower driveway from the street to the house can be used, (e.g., 12 feet). However, this savings in width is offset by the need to provide a turning area so that the cars can maneuver to enter and exit the garage. This added turning area adds significant paved area.

Detached Garage in Rear of Lot: If the garage is detached and located at or near the rear of the lot, then a longer driveway is needed to extend from the street to the rear of the house. The width of this driveway increases in front of the garage to allow cars to enter the various bays. Of course, if an alley exists, then the driveway distance is minimal.

As a low intensity use, driveways are good candidates for porous and permeable pavements or simply paving only parallel strips for the wheels. Another effective control is to route driveway runoff onto adjacent pervious areas instead of directly to the street. This can be done by putting a crown on the driveway as is done for streets.

An effective demand management to reduce the demand for driveways is to reduce the demand for automobiles. Another possibility is to better utilize on-street parking.

Pervious Area on Property

The pervious area on the property is used primarily for lawns, gardens, and wooded areas. This land is used for aesthetic appeal, and recreation for people and pets. Under proposed innovations, this pervious area will be used more intensively to infiltrate stormwater from adjacent impervious areas as well as from precipitation directly onto its surface. At present, pervious areas do receive some of the runoff from impervious areas, primarily from roofs, patios, and some parts of the driveway. Thus, it is important to determine the infiltration capacity of these soils. The infiltration capacity depends on the soil type. Pervious areas can be graded to provide some on-site detention of stormwater, that could then be reused for lawn watering or other purposes. Prince George’s County (1997), MD has developed the idea of “functional landscapes” for on-site management of stormwater.

Alleys

Alleys are regaining popularity as part of new urbanism designs. Alleys can be found in older neighborhoods. They provide access for garages and garbage pickup and other deliveries. Alleys eliminate the need for driveways and thereby permit narrower lot widths. Typical alley widths range from 12 to 16 feet. In addition to this pavement width, aprons to the garages on either side of the alley are needed.

Boulder, CO specifies a 20 foot right-of-way width for alleys. The width of the alley is controlled by the required turning radius for vehicles entering and exiting from the garages and open parking areas. From a safety point of view, alleys greatly minimize the traffic and pedestrian safety hazards associated with vehicles entering and backing out of driveways onto the street. Runoff from alleys is directly connected to the storm sewer system. The runoff moves along the alley by overland flow until it reaches the street inlet. Treatment options would be the same as for other impervious areas with low traffic and parking rates. The demand for alleys can be eliminated by using driveways. The tradeoff on the amount of pavement used for alleys vs. driveways depends on the lot geometry.

Sidewalks

Attractive sidewalks are an inducement to walking. According to Chellman (1997), about 10% of Americans walked to work in 1960. By 1990, the percentage walking to work had decreased to 4%. Sidewalks are an integral part of older cities. With lower density urban development, the need for sidewalks is less critical. If the housing density is very low, then people can walk in the street. Also, a single sidewalk can be used instead of having a sidewalk on either side of the street. Sidewalks can be located adjacent to the street or separated by a six to seven foot wide planting area. The ITE (Southworth and Ben Joseph, 1995) recommends sidewalks with a minimum width of five feet on both sides of the street. Sidewalks are typically constructed of reinforced concrete.

The ULI (1968) recommends sidewalks on both sides of the street if the density exceeds six houses per net acre. They recommend five foot wide sidewalks along collector streets and four foot sidewalks on minor streets. Chellman (1997) recommends sidewalk widths of five feet to provide sufficient room for pedestrians to pass without crowding.

Sidewalks typically drain to pervious areas allowing the runoff to infiltrate into the ground. The notable exception is when the sidewalks are located immediately adjacent to the streets; then the sidewalk runoff becomes directly connected since the drainage goes directly onto the streets. A traditional treatment is sweeping the sidewalk areas to keep them clean and to provide trash containers to discourage littering. Sidewalks can be eliminated if the street is safe for non-vehicular use. See the section on streets for a discussion on this topic.

Curb and Gutter and Swales

The curb and gutter serves a number of functions in residential street design including drainage, providing a barrier for vehicles going from the lot to the street or vice versa, and aesthetics. Two primary types of curb and gutter are the barrier curb and the rolling curb. An alternative is to eliminate curb and gutter and allow street runoff to flow onto adjacent pervious areas. The curb and gutter are about two feet in width. The ITE (Southworth and Ben Joseph, 1995) recommends vertical curb with gutters. Rolled curbs are not recommended. However, the ULI (1968) recommends rolled curbs for most residential areas because they avoid curb cuts for driveways.

According to Khisty (1990), curbs are used for the following reasons:

1. Drainage control
2. Pavement-edge delineation
3. Right-of-way reduction
4. Aesthetics
5. Delineation of pedestrian walkways
6. Reduction of maintenance operations

Planting Strip Between Street and Sidewalk

Many subdivision regulations require a planting strip to separate the sidewalk and the street. The ITE (Southworth and Ben Jospeh 1995) recommends planting strips on both sides of the street with a minimum width of six to seven feet and with the planting strip draining towards the street. A 1990 revision of these standards decreased the minimum planting width to five feet. Boulder, CO specifies an eight foot wide planting area. Planting strips with a width of 15 feet are popular in the western suburbs of Chicago. These planting strips provide a buffer between the street and sidewalk. They also provide a planting area within the right of way for trees. Early subdivision regulations promulgated by the federal government suggested two trees should be planted on each lot. Drainage from these planting areas is directed towards the street. No citations could be found regarding how these areas could function as part of the stormwater drainage system. They could be expected to attenuate noise and air pollution effects to a limited degree.

Overall Right of Way

Required right of way width dimensions for Boulder, CO are (Boulder 1982):

1. Bikeway: 12 ft
2. Alley: 20 ft
3. Residential: 48 ft
4. Residential collector: 68 ft
5. Collector: 81 ft
6. Arterial: 130 ft
7. Freeway: Use AASHTO standards

To this base are added medians, added travel lanes and speed changing lanes, and turn lanes. These right-of-way requirements are typical. The key control option is to take a hard look at existing right-of-way requirements, especially in residential areas, to see whether the requirements could be modified to reduce the generation of impervious area that is providing little or no added value and to encourage the more effective use of pervious areas within the right-of-way.

Will Americans Reduce Auto Use?

Dittmar (1995) outlines a broader context for transportation planning that incorporates some of the above concepts for developing more sustainable transportation systems. In his conclusions, he discusses the feasibility of reversing the trend since World War II of increasing reliance on the automobile. Dittmar says:

> ***In discussions of the issues with transportation officials, their most frequent initial assertion is that Americans love cars and cherish driving, and that any reform effort is therefore somehow doomed. Running a close second are the assertions that Americans are voting with their gas pedals by choosing exurbia, and that building more roadways is simply giving folks what they want. I don't believe this is true. People are responding to a set of signals our society gives them by building ring roads and beltways, subsidizing free parking and suburban development through utility infrastructure, and providing tax incentives that favor car use and suburban home ownership. These signals favor continued sprawl and reliance on cars. Changing these endemic signals by creating incentives to live in the city, eliminating tax biases toward cars, and enhancing livability can send the public new signals.***

With regard to streets, parking, and other major sources of imperviousness, engineers have been the ones who have promulgated these regulations. Hopefully, they can also take the lead in modifying them to create more sustainable communities.

Summary and Conclusions

The results of this discussion on the nature of imperviousness in urban areas show that the quantity of urban stormwater generated per dwelling unit has increased dramatically during the 20^{th} century due to the trend towards more automobiles which require more streets and parking, and the trend towards larger houses, all combined on larger lots. Commercial and industrial areas likewise need much more parking per unit of office space than they did before automobiles. Interestingly, the square footage for residential and commercial areas is less than the support parking requirements. Modern practices dictate devoting more of the city landscape to parking than to human habitat and commercial activities. The net result of this major shift in urban land use is low density sprawl development that generates over three times as much stormwater runoff per family than did pre-automobile land use patterns. Much of these requirements for more and wider streets and parking have been mandated in order to improve the transportation system. Ironically, unlike water infrastructure, these services are not charged directly to the users. Rather, they are subsidized by the general public including non-users. Options for changing this pattern are presented in Chapter 3.

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